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REPORT C
NOISE AND SUPPRESSION

SECTION I
INTRODUCTION

Three specific benefits in achieving low engine noise levels are associated with the augmented turbofan cycle selected for the JTF17. They are:

1. The cycle permits the simple application of noise suppression devices.
2. The turbofan engine noise spectrum has the greatest sound pressure level at a higher frequency than does the turbojet engine and thus the noise from the turbofan engine attenuates more rapidly with distance.
3. The turbofan engine cycle provides operational versatility so that noise generation by the exhaust gases can be reduced by adjustment of flow and velocity in the primary stream and in the fan duct stream.

These benefits of the turbofan engine cycle, when compared to the predicted unsuppressed noise from the engine, permit a variety of techniques for noise suppression to be supplied. These techniques, which are discussed in detail in this report, and their respective noise benefits are:

1. Airport noise:

a.	Ejector effect	4 PNdb (jet noise)
b.	Ejector acoustical liners	2 PNdb (jet noise)
c.	Noise suppressors	4 PNdb (jet noise)

2. Approach noise:

a.	Resonant acoustical liners	15 db (OASPL; fan noise)
b.	Blade/vane matching	6 db (OASPL; fan noise)
c.	Blade/vane spacing	4 db (OASPL; fan noise)
d.	Ejector acoustical liners	2 db (OASPL; fan noise)
e.	Ejector effect	3 PNdb (jet noise)
f.	Noise suppressors	3 PNdb (jet noise)
g.	Ejector acoustical liners	2 PNdb (jet noise)

3. Community noise:

a.	Resonant acoustical liners	13 db (OASPL; fan noise)
b.	Blade/vane matching	6 db (OASPL; fan noise)
c.	Blade/vane spacing	4 db (OASPL; fan noise)
d.	Ejector acoustical liners	2 db (OASPL; fan noise)
e.	Ejector effect	3 PNdb (jet noise)
f.	Noise suppressors	3 PNdb (jet noise)
g.	Ejector acoustical liners	2 PNdb (jet noise)
h.	Matching effects	5 PNdb (total engine noise)

On the basis of analysis and measurements, P&WA believes that the following FAA noise objectives can be obtained:

1. 1500 feet from centerline of runway 116 PNdb
2. 3 statute miles from start of takeoff roll 105 PNdb
3. 1 statute mile from runway on approach 109 PNdb

A summary of current and potential JTF17 noise suppression for each of the above conditions is presented in figures 1 through 3. Unsuppressed noise values have been established using the methods defined at the beginning of the following section, Section II (Cycle Noise).* Engine model specification values of fan and exhaust noise suppression have been applied to define the curves labeled "current suppression."

Noise levels that will be achieved through the application of suppression devices developed during Phase III are shown as potential suppression on each curve. The shaded areas represent the increase in effectiveness of suppression devices that will be developed during this period.

In Section II (Cycle Noise), predicted unsuppressed single engine noise levels are presented. These are followed by a description of the proposed noise development program. Section III (Suppression Devices), gives a summary of available suppression methods and estimates effect of each method when applied to the engine. Unless otherwise indicated, suppression devices are identical for prototype and production engine designs. Section III concludes with a description of the Phase III Suppressor Development Program.

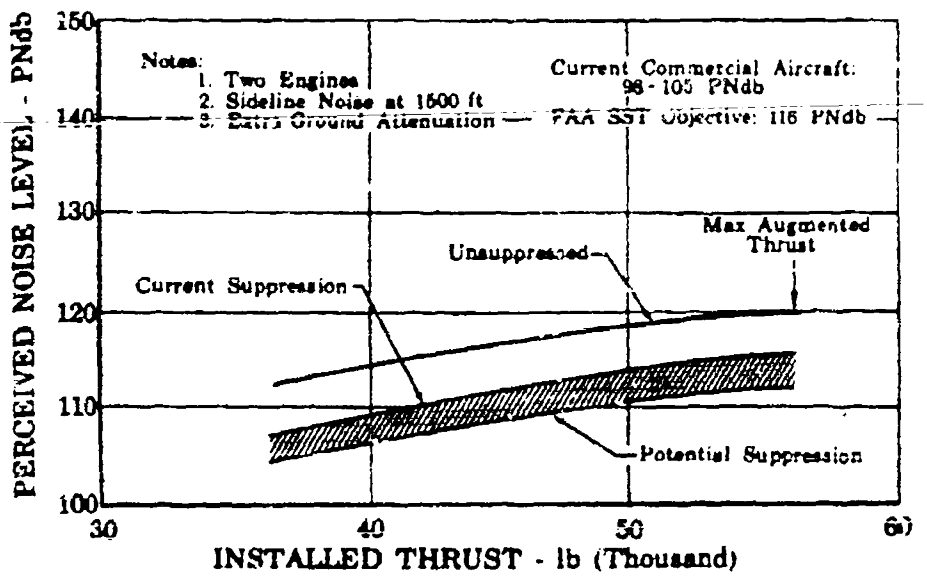


Figure 1. Predicted Turbofan Airport Noise Levels FD 16948 CI

*Standard SAE procedures (AIR 876) require adjustments for the number of engines in determining aircraft noise levels. The sound produced by four engines is used for all flight conditions, and that produced by two engines is considered during operation on the ground. Octave band sound pressure levels are presented for a single engine, since this distribution is predicted to be equal for each engine at a common thrust level.

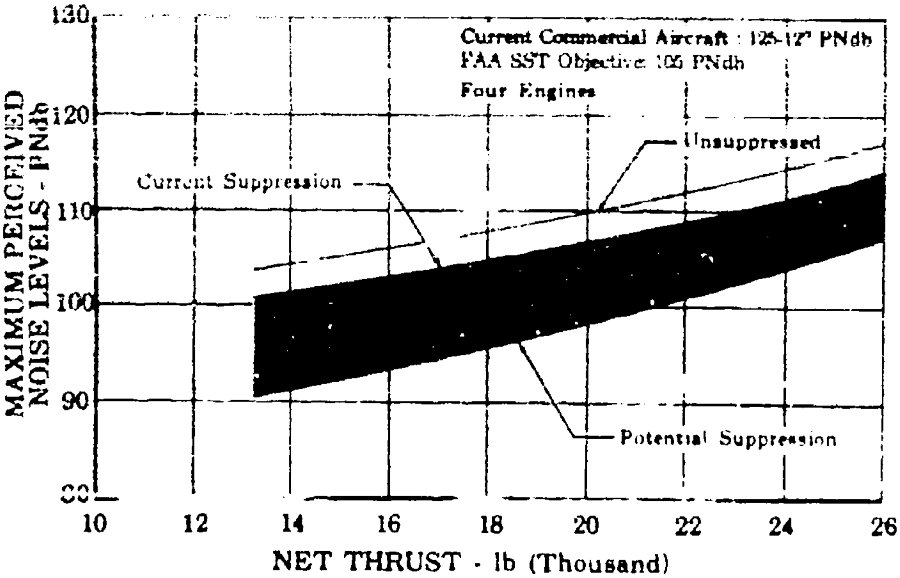


Figure 2. Predicted Turbofan Noise Levels Typical of Flight Profiles at Thrust Cutback After Takeoff — FD 16949 CI

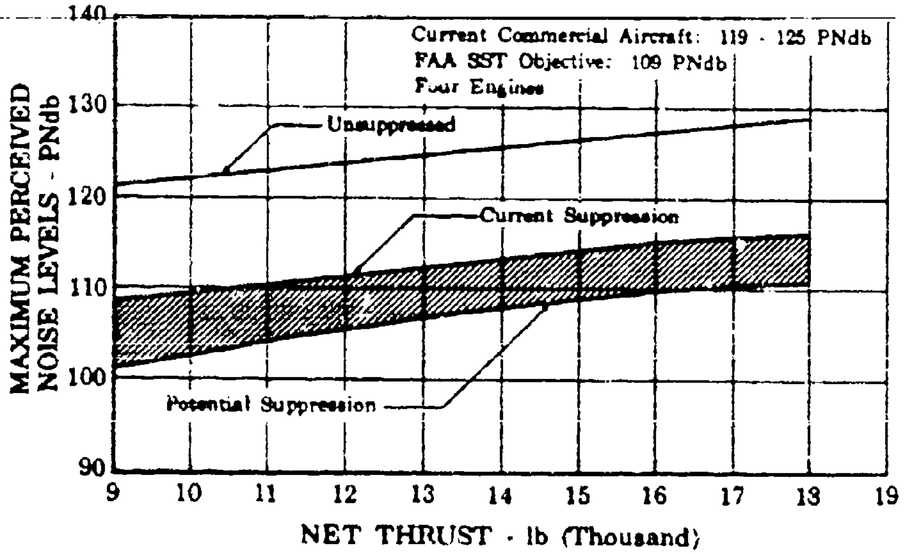


Figure 3. Predicted Turbofan Noise Levels Typical of Flight Profile at Approach Conditions — FD 16950 CI

SECTION II
CYCLE NOISE

A. PREDICTED ENGINE NOISE LEVELS

P&WA's experience in noise measurement and control has shown that the noise produced by the turbine is not perceptible in the presence of the other noise sources in the engine and for this reason is not significant in this evaluation of JTF17 engine noise. Therefore, this small noise source is not discussed in this section of the proposal. The significant noise sources in the turbofan engine are the primary exhaust gas stream, the fan duct exhaust gas stream, and the fan. These sources and the control of these sources will be discussed in detail in this volume.

It should also be noted that methods for control of the noise emitted from the front of the engine are not discussed as a noise development program of the engine manufacturer in this proposal. P&WA believes control of this noise can be readily accomplished by appropriate treatment of the inlet and the associated ductwork. Continuous support of the airframe manufacturer's inlet noise control development program will be provided by P&WA during the engine test and noise programs. Inlet noise control methods will be evaluated during Phase III in engine tests with the inlet installed. Engine noise levels transmitted forward to the inlet and reduction in these noise levels by noise control features incorporated in the engine design will be provided to the airframe manufacturer to assist the implementation of the airframe manufacturer's inlet noise control program.

1. Prediction Procedure

The noise predictions discussed in the following paragraphs are based upon current SAE-approved methods supplemented by techniques developed by P&WA. These methods are applicable to an engine that incorporates no features specifically designed to minimize noise.

Exhaust noise was estimated using engine performance parameters calculated by the P&WA engine specification computer programs in the prediction method defined by SAE Document AIR 876. The resultant octave band sound pressure levels were then added to predicted fan sound pressure levels calculated by the system described in Item 9 of the P&WA Phase II-A Final Report. Values for preceived noise were then obtained using the method of SAE Document ARP 865. Required adjustments for distance from the sound source were performed in accordance with SAE Document AIR 876.

2. Airport Approach Conditions

Engine net thrust one mile from touchdown during airport approach will be in the approximate range of 9,000 to 18,000 lb. For this net thrust range, the relationship between the individual noise sources and the magnitude of the respective contributions to total engine noise is presented in figure 1.

The unattenuated fan is the predominant noise source throughout the thrust range illustrated. By means of suppression devices described in Section III, however, noise from this source can be attenuated to the

level produced by the exhaust gases or possibly even lower. The versatility of the turbofan cycle also provides an opportunity for further reductions in fan and exhaust gas noise through the operational techniques described in Section III.

Octave band sound pressure levels at a representative approach thrust condition of 12,000 pounds of net thrust are presented in figure 2.

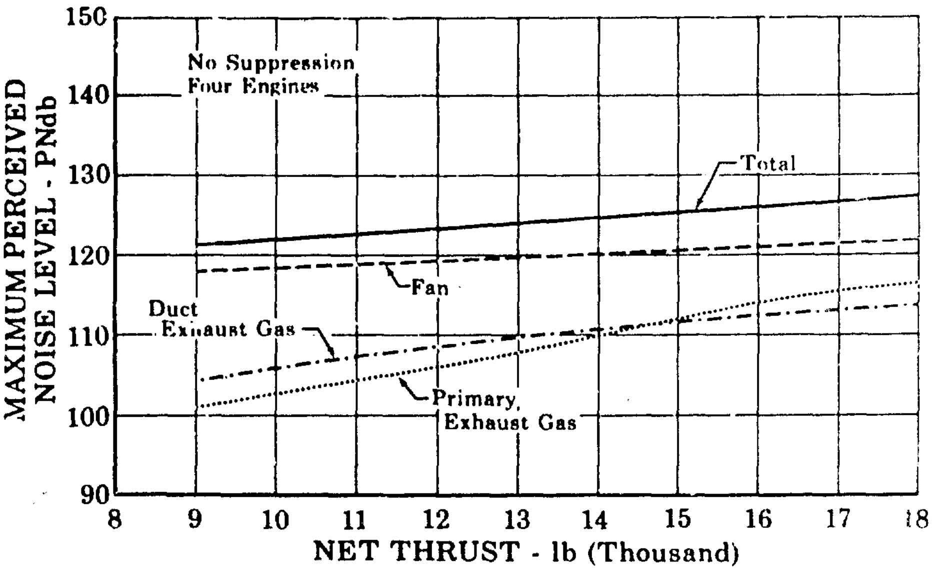


Figure 1. Predicted Turbofan Noise Levels Typical of Flight Profile at Airport Approach — FD 16750 CII

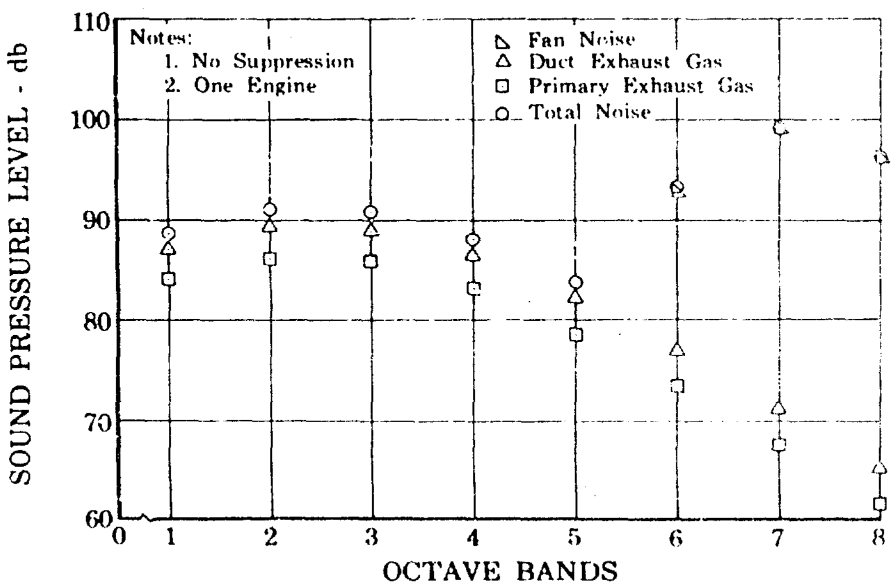


Figure 2. Predicted Sound Pressure Levels Typical of Flight Profile at Airport Approach — FD 16751 CII

3. Community Noise

Power after takeoff is shown in figure 3 for the range of 15,000 to 27,000 lb net thrust. Because of a substantial increase in altitude over that of airport approach, total noise is expected to be considerably reduced with respect to an observer on the ground even though net thrust is higher. The predicted values are given in figure 3.

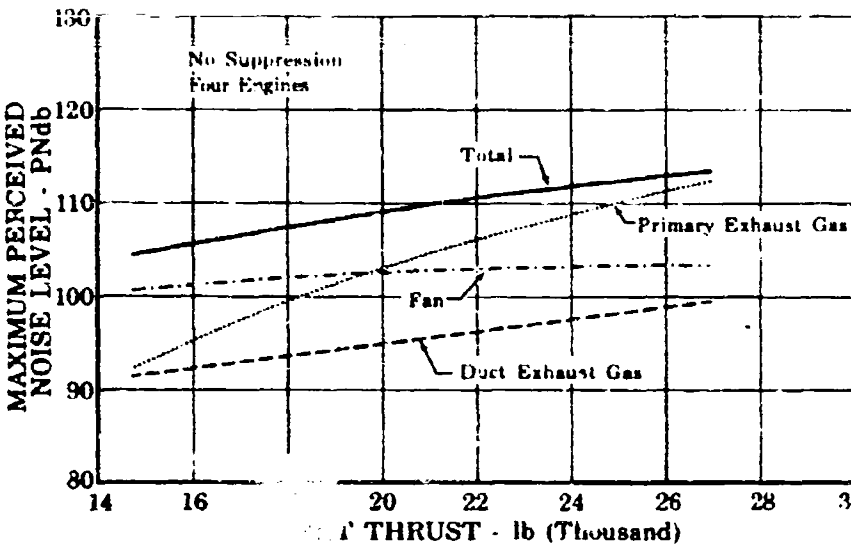


Figure 3. Predicted Turbofan Noise Levels Typical of Flight Profile at Thrust Cutback after Takeoff — FD 16752 CII

At the lower level of the thrust range that may be expected at flight conditions under which community noise will be evaluated, the relationship between the three individual noise sources is similar to that previously shown during airport approach. As net thrust continues to increase, however, several important characteristics may be observed:

1. The slope of the fan noise curve is small and thus produces an almost negligible increase in noise as net thrust is increased.
2. Duct exhaust noise does not contribute significantly to total noise and exhibits an almost negligible increase as net thrust is increased.
3. Noise from the primary stream increases considerably and is the primary cause for a significant increase in total noise as net thrust is increased.

Under these conditions, the operational flexibility of the engine provides a significant advantage as described in Section III. A predicted octave band distribution of engine noise representative of the community thrust range is provided in figure 4.

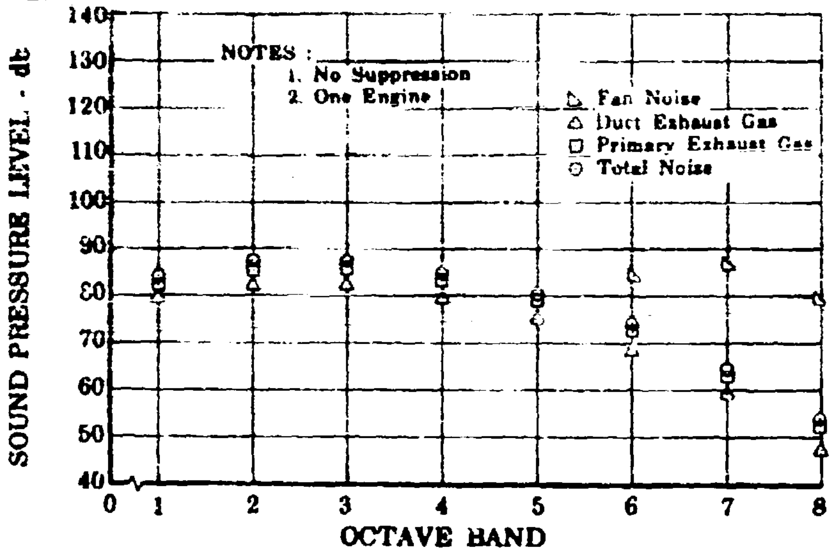


Figure 4. Predicted Sound Pressure Level Typical of Flight at Cutback after Takeoff

FD 16753
CII

4. Airport Noise

For the range of engine net thr c to be used during takeoff, exhaust noise will be greater than fan-generated noise, as shown in figure 5. At high values of nonaugmented thrust, exhaust noise from the primary stream is expected to be predominant. In the augmented thrust range, exhaust noise from the fan duct stream will exceed that from the other noise sources. Effective exhaust noise suppression can be obtained throughout this thrust range with conventional suppressors and the suppression effect of the reverser-suppressor. A representative octave band distribution for this thrust range is shown in figure 6.

B. PROPOSED NOISE DEVELOPMENT PROGRAM

1. Introduction

P&WA experience in analyzing the fan noise generation process extends through the past decade. A paper presenting the results of these studies received the Manly Memorial Award in 1961. U. S. Patent No. 3,194,487 was awarded to P&WA in 1963 for methods of applying these results to reduce fan noise. The extensions to this work that will continue through Phase III of the SST engine development program are discussed in this section.

Hundreds of full-scale and anechoic chamber model tests of various nozzle and ejector configurations have also been conducted by P&WA over the past few years. Although designs were found that provided useful amounts of exhause noise attenuation, two major shortcomings existed:

a. Performance degradation of undesirable magnitudes. This has been corroborated by published NACA test data (figure 7).
b. A lack of understanding of the physical processes actually providing the attenuation.

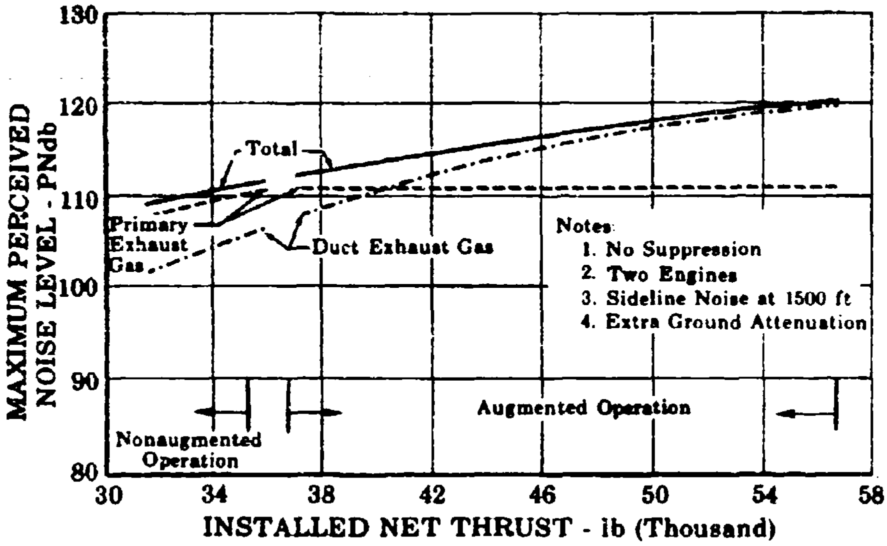


Figure 5. Perceived Sideline Noise at Takeoff FD 16973 CII

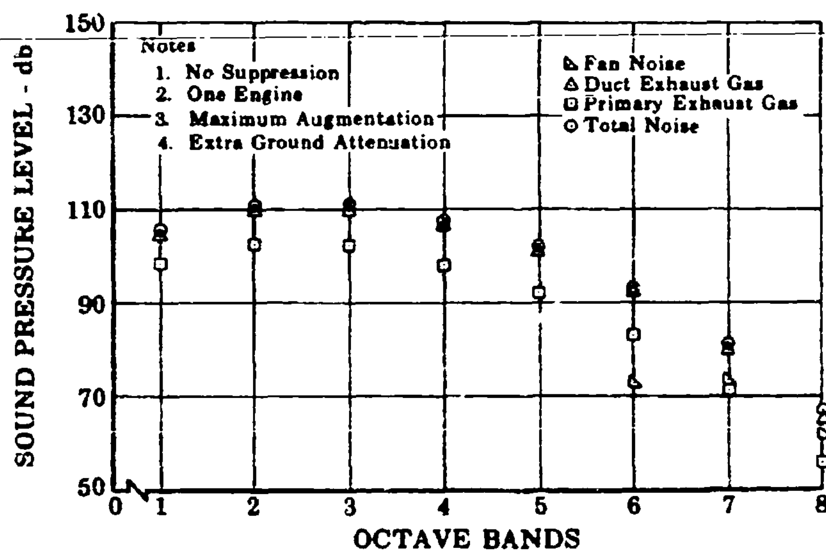


Figure 6. Predicted Sound Pressure Levels at Takeoff FD 16755 CII

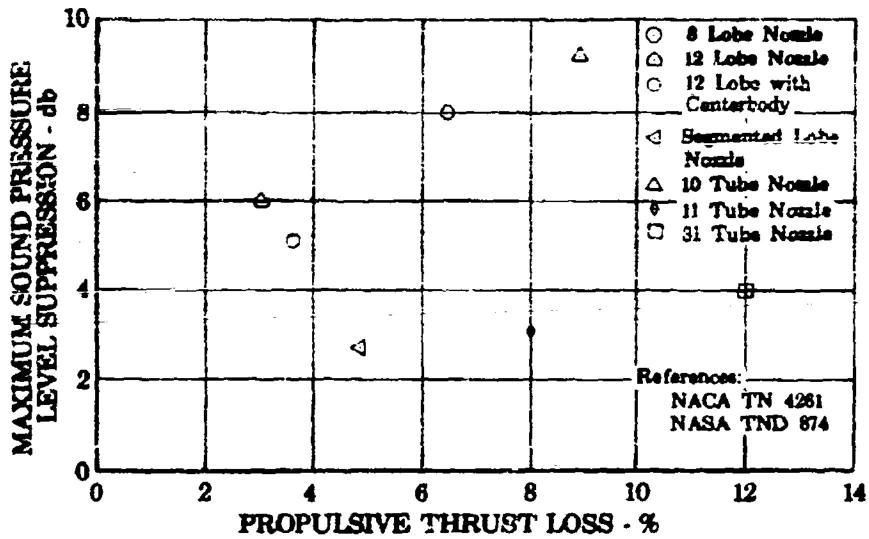


Figure 7. Exhaust System Model Test Data Comparison of Maximum Sound vs Thrust Loss — FD 17811 CII

In contrast, recent tests have been conducted to define the mechanics of exhaust noise generation. Clear demonstrations have been developed that show distinct differences in the turbulence developed downstream of nozzles with different contours. Some correlations have been established between the results of these flow visualizations and noise produced by the exhaust gas. Improved analytical tools are now being planned to continue this work during development in Phase III.

The noise development program that will be conducted by P&WA during Phase III encompasses the following three areas:

1. Exhaust noise generation
2. Fan noise generation
3. Analysis of JTF17 engine noise.

Each of these programs are treated separately in the following paragraphs.

2. Exhaust Noise Development Program

Experience gained during Phase II-C with water table and model tests indicates that the geometry of the engine exhaust system has a critical influence upon the intensity of the noise produced by a turbofan engine. Particularly important are the contours of the primary and duct nozzles, the locations and lengths of the blow-in doors, and the contour of the reverser-suppressor. Further evaluation of the effects of these and related variables is necessary to minimize the noise produced by the JTF17 exhaust gas. Tests will be conducted in an outdoor, model test stand currently in the design and procurement stage for installation at the FRDC. This facility (figure 8) will provide the following conditions for testing model exhaust systems up to one-fifth of full JTF17 size.

1. Airflow of up to 18 lb/sec at pressures of at least 60 psia
2. Single or dual airflow with provisions for secondary air supply for testing models of turbofans or turbojets
3. Independent control of temperature, flow, and pressure for each airstream, with a maximum temperature capability of 2500°F
4. Thrust measurement capability
5. Schlieren photography capability
6. Sound measurement capability.

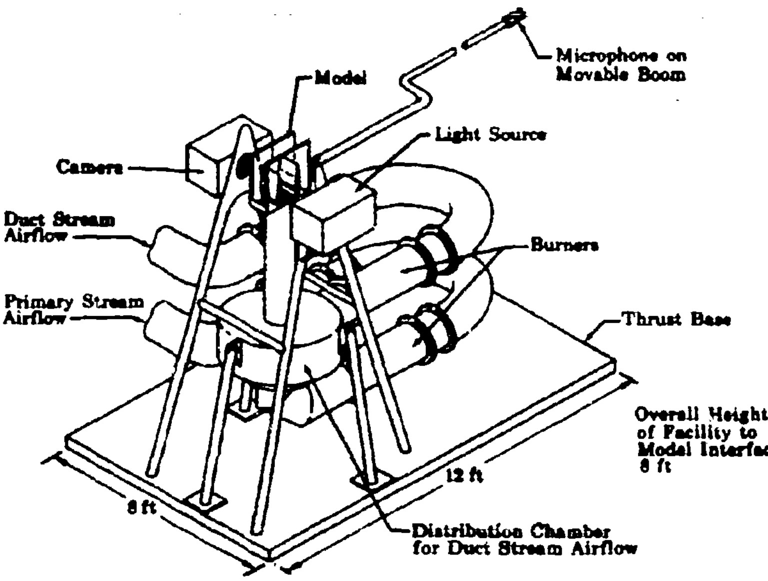


Figure 8. Model Test Facility with Schlieren Model Mounted — FD 16756 CII

Initial tests of engine exhaust systems conducted on this test facility will utilize two-dimensional models. In this manner, correlation will be established between the development of the turbulent noise-generating region as observed on the water table, which is also two-dimensional, and that observed with actual gas flow under exact conditions of Mach number, weight flow, temperature, and pressure. This correlation will be established through the use of Schlieren photographs of the two-dimensional model and is expected to provide data that will allow for more extensive use of the water table as a design tool.

Further exhaust system tests with the model test facility will be conducted using three-dimensional models. Noise measurements taken during this phase of the development will provide a final check on the theory developed in previous analyses and two-dimensional testing prior to its application to full-scale hardware.

Model tests that have already been conducted show that, because of the small scale of the models, inaccurate duplication of airflow may be encountered, even with precise geometric reproduction. For example, tertiary airflow introduced through the blow-in doors may be related to a relatively large Reynolds number and a turbulent boundary layer in the

full-scale engine. With a small-scale model, however, the reduced dimensions may result in a Reynolds number providing a laminar flow condition. Thus, mixing of the tertiary air in the ejector may be expected to be different in each case, with the possibility of significantly different effects upon the noise generated. Model testing conducted during Phase II-B has indicated ways of correcting for these effects once they are recognized. For example, identical Reynolds numbers for the model and for the full-scale engine can be established by adjusting the characteristic dimension (L) of the model in the following equation:

$$Rey = \frac{\rho V L}{\mu}$$

where: ρ = density
V = stream velocity
μ = viscosity

This could be accomplished in a simulation of tertiary air injection by increasing the length of the blow-in door on the model. Sufficient correlation between full-scale and model tests will be established to provide confidence in the accuracy of the model test results.

3. Fan Noise Development Program

Previously referenced fan noise investigations conducted by P&WA have established that the pressure gradients produced along the surfaces of blades and vanes are responsible for the audible noise produced by a compressor. The effect upon noise of variations in this aerodynamic loading will be investigated in detail as a part of the Phase III development program for the JTF17 engine.

A representative pressure distribution for an airfoil is shown in figure 9a. The large pressure differential illustrated would, for example, be produced on the surfaces of a blade. Analysis indicates that the strength of the audible noise produced is proportional to the pressure differential, while the frequency of the sound is a function of the number of blades in the stage and rotor speed. It follows, therefore, that by providing a reduced pressure differential, noise may also be reduced.

A second representative pressure distribution is presented in figure 9b. The total force acting on the airfoil is the same in this example as in the previous case, however, the loading of the airfoil has been altered to minimize the pressure differential across the airfoil. Methods of achieving this type of airfoil loading and the effects of loading upon fan noise will be evaluated using the six-tenth scale compressor rig described in the compressor development section of this proposal. Narrow frequency band analyses will be conducted on the sound recordings made during rig operation. Microphones will be located in the discharge duct of the rig. Configurations found to have significant value will be evaluated further during full-scale engine tests.

An additional objective of the fan noise development program will be to determine the generating mechanism of the combination tones or "buzz-saw" noise produced by a fan at high rotor speeds. This noise occurs at

supersonic tip speeds and is characterized by a multitude of high pressure peaks having frequencies up to approximately 4000 cps. Concurrent programs will be conducted at the Florida Research and Development Center and at the East Hartford facilities to define the source and means of control of this phenomenon. These activities will be conducted in scaled compressor rigs, and results will be verified in full-scale engine tests. Initial investigations have already been started in East Hartford because of the potential application to engine development programs being conducted by that facility.

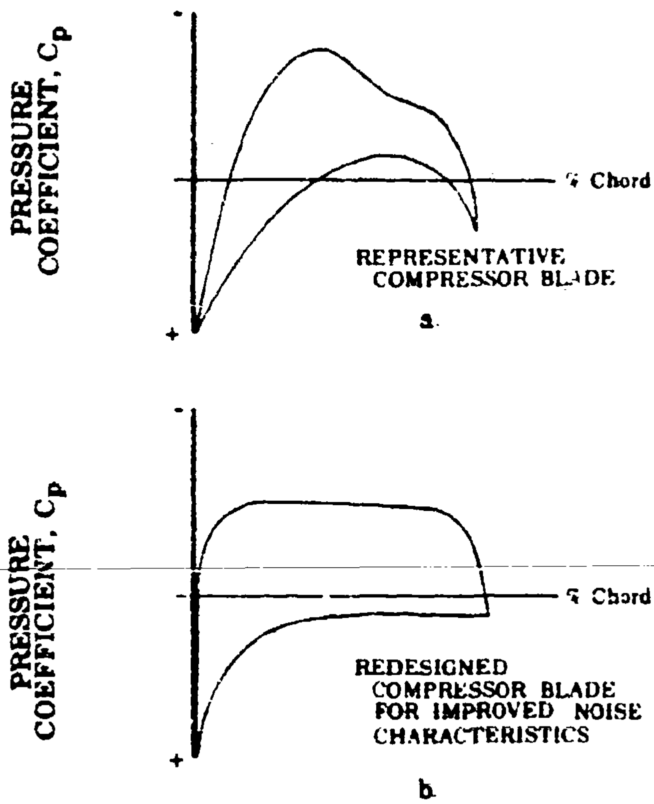


Figure 9. Comparison of Pressure Distribution on Compressor Blades — FD 16757 CII

4. Engine Noise Analysis

Considerable data have already been acquired in the JTF17 engine development program during initial running of engines FX-161 and FX-162. These data have shown areas where sound suppression techniques would have the greatest benefit. The engines were operated at conditions simulating both thrust cutback after takeoff and airport approach thrust.

A narrow-band spectral analysis of exhaust noise recorded from the first test of engine FX-161 at airport approach engine speed (N_1 = 4300 rpm) is shown in figure 10. Characteristic peaks in sound pressure level are shown to exist at the first rotor fundamental blade passing frequency (3150 cps), in the range of the second rotor fundamental (5300 cps), and

at the first harmonic of the first rotor blade passing frequency (6300 cps). The existence of these discrete frequency pressure peaks contributes 10 to 12 db to the overall sound pressure level produced by the fan.

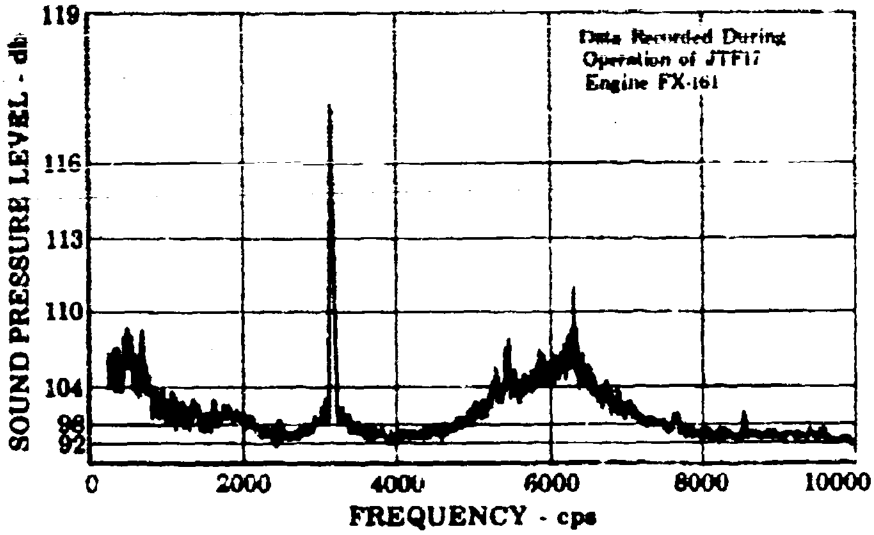


Figure 10. Spectral Analysis of Exhaust Noise at Aircraft Approach Speed FD 16758 CII

A different situation has been found to exist at fan speeds (N_1 = 5200 rpm) required following thrust cutback after takeoff, as shown in figure 11. Under this condition, blade tip speeds are well into the supersonic region. As a result, combination tones are produced at frequencies up to almost 4000 cps, which contributes significantly to the noise produced by the fan. At the same time, discrete frequency noise remains significant under this condition and contributes 8 to 10 db to the overall sound pressure level produced by the fan.

Engine test stands that now exist at the Florida Research and Development Center are not suitable for far-field noise measurements due to the existence of permanent blast walls and extremely uneven terrain in the sound field. To compensate for these shortcomings, the recordings referenced above were made with microphones located 20 feet from the plane of the engine exhaust.

Noise measurements during the Phase III development program will be made on a new facility constructed primarily for this purpose and described as the noise-reverser test stand in the facilities section of this proposal. The quality of the noise measurements made on this stand will be enhanced by the following features of the facility:

1. Engine centerline height greater than two nozzle diameters above the ground
2. Clear and level ground extending for a distance of 500 feet from the engine.

3. On-site facilities for meteorological measurements
4. Thrust and engine parameter recording capability
5. Permanently located microphone positions
6. Low background noise levels.

The noise recordings will be so made as to allow for both octave band and narrow frequency band analysis. In addition, pressure transducers will be located in the fan duct walls to obtain sound intensity data for use in the design of acoustical liners.

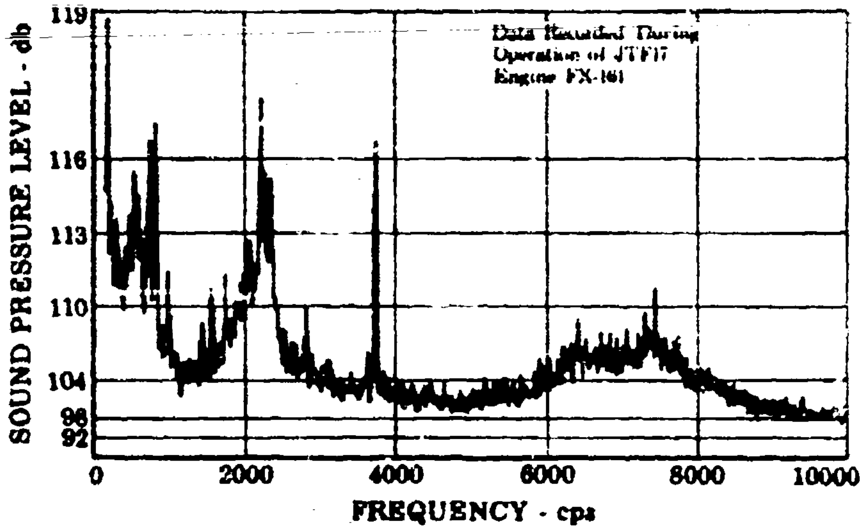


Figure 11. Spectral Analysis of Exhaust Noise at Thrust Cutback after Takeoff — FD 16759 CII

A program will be conducted on this facility to establish the amount of noise reduction possible by the operational versatility of the engine. As discussed below, this program will include investigations of exhaust noise matching and of the effect of duct heating on fan noise.

To accelerate the acquisition of noise data, a temporary facility is being constructed (figure 12). This facility will be completed in the latter part of Phase II-C and will permit satisfactory measurement of near- and far-field exhaust noise.

a. Exhaust Noise Matching

As shown in figures 1 and 3, and discussed in Section III, analyses of predicted engine noise indicate that the exhaust noise produced by the fan duct stream and the primary stream are not well matched in the nonaugmented thrust range with normal engine control scheduling. Figure 3 shows, for example, that the noise produced by the unsuppressed primary exhaust gas at 20,000 lb total engine thrust is predicted to be more than 8 PNdb higher than the noise produced by the duct exhaust gas. If the noise level of the primary exhaust was reduced while the noise level of the duct exhaust gas was increased until the two levels were equal,

total noise would be reduced. Two identical noise sources produce a total noise level 3 PNdb higher than the common level of each. By reducing primary exhaust noise 4 PNdb and increasing duct exhaust noise the same amount, a common level of 99 PNdb would be obtained in the above example. Total exhaust gas noise under these conditions could be expected to decrease by about 1 PNdb.

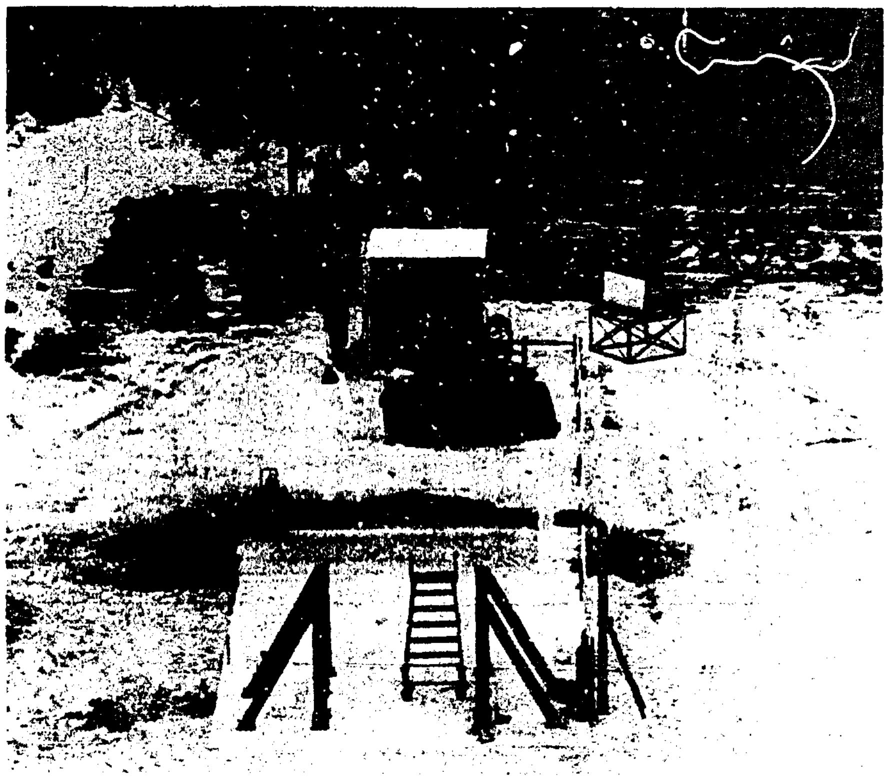


Figure 12. Temporary Full-Scale Engine Noise Test Facility FC 13323 CII

While the matching of exhaust gas noise produced by the JTF17 engine is analogous to the above example, the amount of improvement gained is a complex function of engine operation. When the primary exhaust stream produces more noise than the fan duct, improved matching can be achieved by obtaining additional thrust from the duct with duct heat. Constant total engine thrust can be maintained under these conditions by reducing primary fuel flow. With the JTF17 engine, however, fan speed is also reduced by this procedure, which provides an additional source of total engine noise reduction. Specific cases of noise reductions gained through improved exhaust noise matching are examined in Section III (Suppression Devices).

b. The Effect of Duct Heating on Fan Noise

Fan noise transmitted through the fan duct must pass through the annular duct heater located in the flow stream. Operation of the duct heater is expected to have an attenuating effect upon the pressure pulses produced by the fan that should reduce the effect of fan noise when operating in this mode.

SECTION III
SUPPRESSION DEVICES

A. INTRODUCTION

The suppression devices to be used must be designed with consideration that the dominant noise sources change with the engine throttle setting and are thus different for takeoff and approach.

At the low thrust levels used during airport approach and power cutback after takeoff, the fan noise predominates, but jet noise suppression is also needed. Under these conditions the fan noise can be controlled by acoustical absorbing liners, careful selection of blade numbers, and selection of spacing between blades and vanes to reduce the noise generated.

Demonstrated techniques of fan noise treatment have shown a 15 db per octave band reduction of fan noise. P&WA believes that through the use of available acoustical materials and the maximum use of the noise signature characteristics of the turbofan engine, the potential fan noise suppression is no less than 22 [illegible].

Similarly, exhaust gas noise suppression devices similar to those described in this section have demonstrated at least 3 PNdb reduction in this noise. The attainment of significantly greater reduction appears to be possible within the SST development period.

B. FAN

1. Methods Available

The basic noise control versatility of the JTF17 duct burning turbofan engine provides a variety of ways to achieve large reductions in fan noise. This flexibility allows the use of several effective methods of fan noise control simultaneously. Although the primary objective for the use of these methods is to control the fan noise component of exhaust noise, reduction in fan noise transmitted forward of the engine is also anticipated. Measured reductions in noise obtained through these methods, which reduce requirements for fan noise suppression by the engine's inlet, will be coordinated with the airframe manufacturer. Verification of these improvements will be provided by P&WA through engine tests with the inlet installed.

Acoustical or sound absorbing liners of the resonant and nonresonant types will be used in the diffuser section of the fan duct to absorb noise. In addition, several fan modifications are incorporated into the engine design to minimize the noise generated by the fan. Each of these methods of noise control is discussed in detail in the following paragraphs.

2. Acoustical Liners

Sound absorbing liners, often called acoustical liners, provide effective noise control when mounted on the walls of the fan duct. In operation, the liners absorb sound energy transmitted downstream of the fan in the duct, allowing less sound energy to reach the duct exit, and, as a result, the radiated sound level is reduced. These liners may be either resonant or nonresonant as discussed in the following paragraphs.

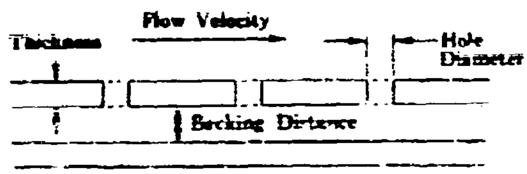
a. Resonant Liners

Helmholtz resonator theory provides the basis for the operation of resonant acoustical liners. A Helmholtz resonator is an acoustical absorber consisting of a volume of air communicating with a sound source through a small channel. If the interior volume of the resonator is large compared to the channel, the change in pressure (due to the incident waves) at the aperture of the channel will set the mass of air in the channel in vigorous motion while the air in the interior of the resonator is periodically compressed and rarified. The kinetic energy is concentrated in the channel, while the interior volume acts as the potential energy source. The resonator is analogous to a simple mass-spring system. The interior volume represents the spring, and the air in the channel is analogous to a vibrating mass. The energy loss in the system stems from the friction at the side walls of the channel and parallel plate surfaces and from turbulence losses. For a liner, the space between the liner and the wall is regarded as a collection of volumes (or springs) where equal volumes are allocated to each channel or hole. No partitions are required to physically separate those volumes if the incident waves are normal to the liner and if the internal pressure is uniform. A pressure rise at the aperture of each resonator will tend to accelerate the mass in the hole, compressing the interiors, which in turn exerts a force tending to return the mass to its original position.

A typical resonant liner cross section is shown in figure 1 with identification of the variables influencing the design. Sufficient work has been completed by P&WA to develop an analytical design method incorporating these parameters that can be used to optimize the absorption of sound energy under specific duct conditions. Close agreement has been found between analytical results and those produced by impedance tube tests, as illustrated in figure 2. A detailed description of this analytical design method is contained in P&WA Report TDM-1287. The P&WA impedance tube test facility is shown in figure 3.

As expected from the numerous variables contributing to the degree of sound absorption of a resonant liner, considerable design flexibility exists. Sound absorption capability is expressed by the absorption coefficient (α) defined as the fraction of the incident energy that is absorbed. A typical set of design curves for a resonant liner is given in figure 4. When applied to the JTF17 engine fan duct, minimum backing depth may be used with a large hole size and open area ratio to provide a liner design of minimum weight.

The absorption coefficients remain reasonably high for resonant liners operating at frequencies other than resonance. As shown in figure 5, absorption coefficients above 0.5 can be obtained with a single liner design over a range of approximately 5000 cps. The use of multiple designs for different sections of the fan duct can further improve this condition.



DESIGN VARIABLES

1. Sound Pressure Level
2. Frequency
3. Pressure
4. Temperature
5. Density
6. Specific Heat Ratio
7. Absolute Viscosity
8. Open Area Ratio
9. Flow Velocity
10. Material Thickness
11. Hole Diameter
12. Backing Distance

Figure 1. Resonant Acoustical Liners FD 16832 CIII

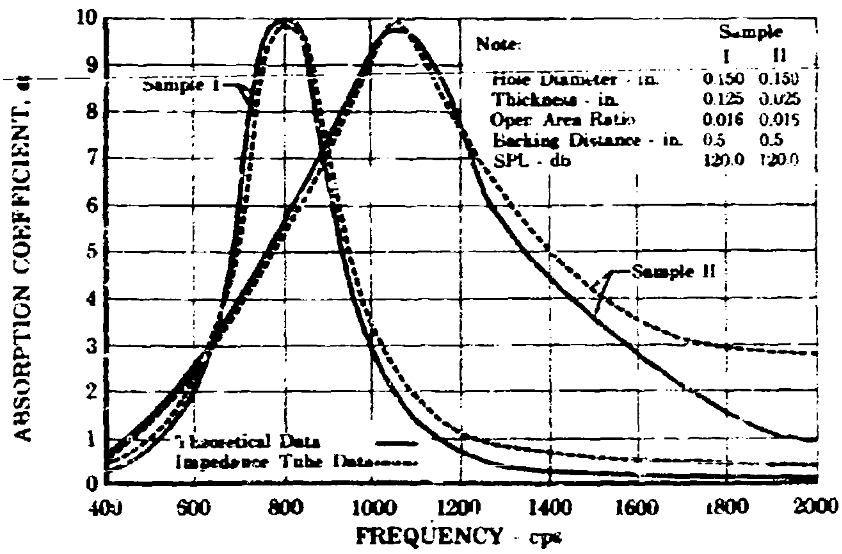


Figure 2. Comparison of Theoretical Absorption Coefficients with Experimental Data FD 16831 CIII

Figure 3. Impedance Tube Facility FD 17453 CIII

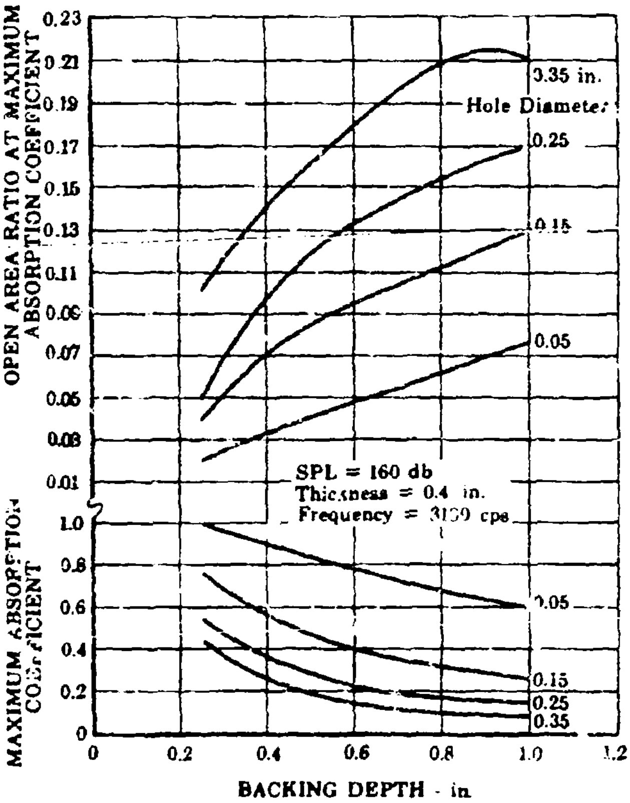


Figure 4. Design Curves for Resonant Liners FD 16830 CIII

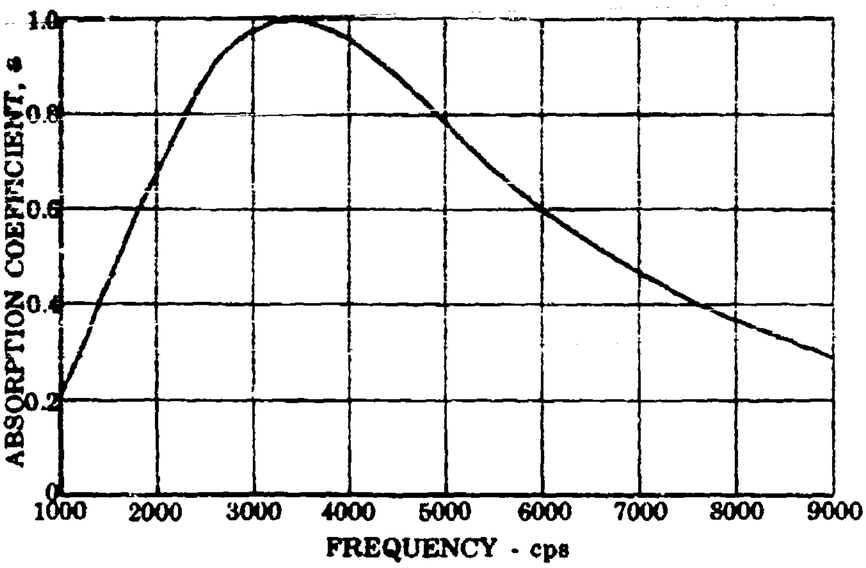


Figure 5. Typical Absorption Coefficient of Resonator Liners

FD 16829
CIII

b. Nonresonant Liners

A thin sheet of permeable material produced by felting and sintering can be made to act as an effective acoustical absorber. Commercially available material has been tested extensively to evaluate the fan noise absorption capability when applied to the fan duct walls. By providing an air gap between the liner and an impervious wall, attenuation of noise-producing pressure pulses is gained by:

1. The capacitative reactance of the port volume
2. Turbulence losses resulting from flow through the ports.

Nonresonant liners may be adjusted for optimum absorption at a specific frequency by adjustment of flow resistance and backing depth. Under these conditions, relatively high absorption coefficients can be maintained over a wide frequency range such as shown previously for resonant liners.

c. Test Results

The suppression provided by an absorption liner may be related to total liner surface area, the size of the duct annulus, and the geometry of the duct. Provided that liner design is based upon the optimization of the variables specified in figure 1, suppression of fan-generated noise will:

1. Increase with liner surface area
2. Decrease with increases in duct annulus size
3. Increase as the duct shape becomes less cylindrical with the addition of duct sections that are not parallel to the engine axis.

An analytical relationship between those factors that would provide an accurate prediction of the attenuation that might be expected from a specific nonresonant liner installation has not been developed. However, liner suppression tests with duct sections similar to that of the JTF17 engine have been conducted. A representative installation is shown in figure 6. Tests were conducted in a dual reverberation chamber with flow velocities up to 525 ft/sec using both resonant and nonresonant liners. During these tests, the ratio of the liner length to annulus width (L/D) was approximately 2.5. In each instance, a single 20-inch section of absorptive material on one wall of the duct was evaluated.

The results of tests using a resonant liner are shown in figure 7. The liner absorption coefficient was adjusted by altering the air backing distance to provide maximum attenuation in the 7th-octave band. With a flow velocity of 300 ft/sec, an average attenuation of 10 db resulted. Although no adjustments were made to the liner to optimize absorption for a flow velocity of 525 ft/sec, absorption in the same octave band still averaged approximately 8 db.

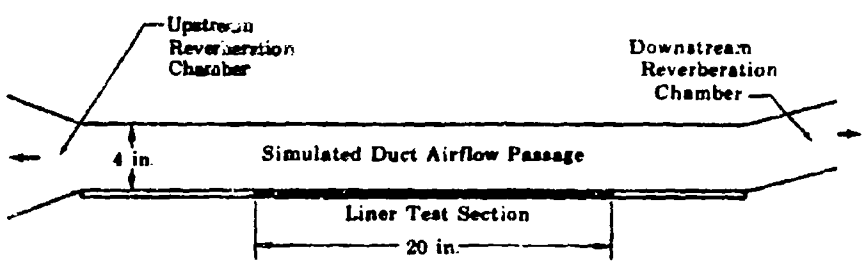


Figure 6. Duct Section for Liner Noise Attenuation Tests FD 16828 CIII

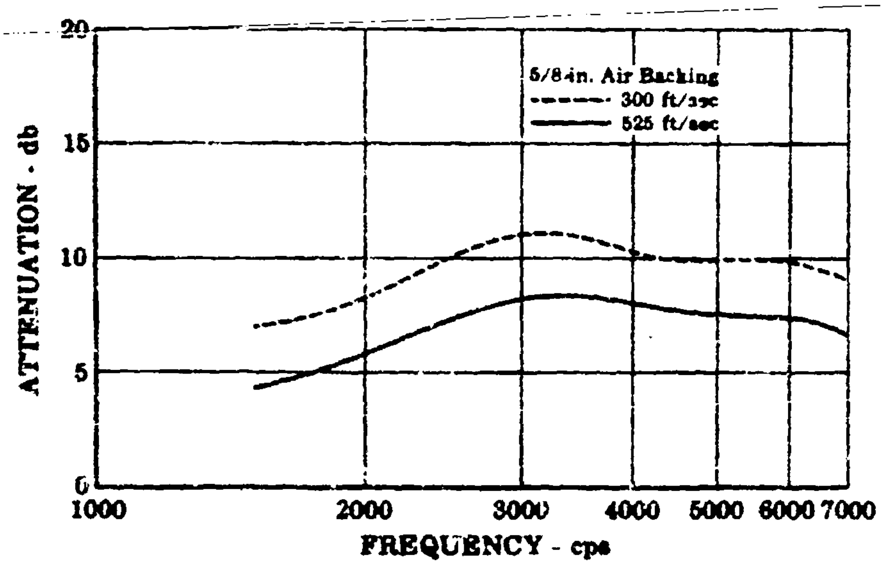


Figure 7. Fan Duct Section Treated With Perforated Platewire Screen FD 16827 CIII

Additional tests with the same duct section and facility were conducted at a flow velocity of 525 ft/sec using a nonresonant liner of the same length (65% density Feltmetal) with a 1-inch backing distance. In figure 8, the results of this test are compared to those for a resonant liner. Attenuation of approximately 2 db less throughout the frequency range tested was found for the Feltmetal. Notably, both types of liners were found to provide effective noise attenuation over a broad range of frequencies in the audible range.

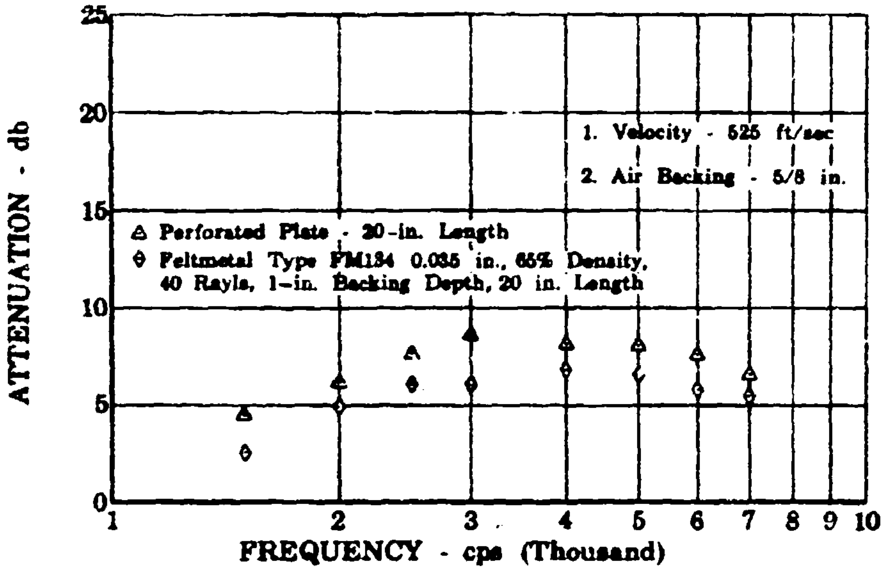


Figure 8. Comparison of Attenuation of Resonant and Nonresonant Liners

FD 16826
CIII

d. JTF17 Engine Application

Results of the rig tests just discussed are directly applicable to attenuation of fan noise within the JTF17 engine fan duct by acoustical liners. Flow velocities range from approximately 300 to 600 ft/sec in the engine fan duct at the engine thrust settings where fan noise is expected to be important, i.e., dominant over exhaust noise.

As shown in figure 9, many potential locations for acoustical liner installations exist within the duct. Studies are currently being conducted of various locations and installation methods that would provide minimum weight penalties for the attenuation gained. These include:

1. Diffuser walls
2. Diffuser walls with flowsplitter in 17-inch section downstream of fan discharge
3. 12-inch section and 17-inch section modified to eliminate line of sight
4. Duct heater section.

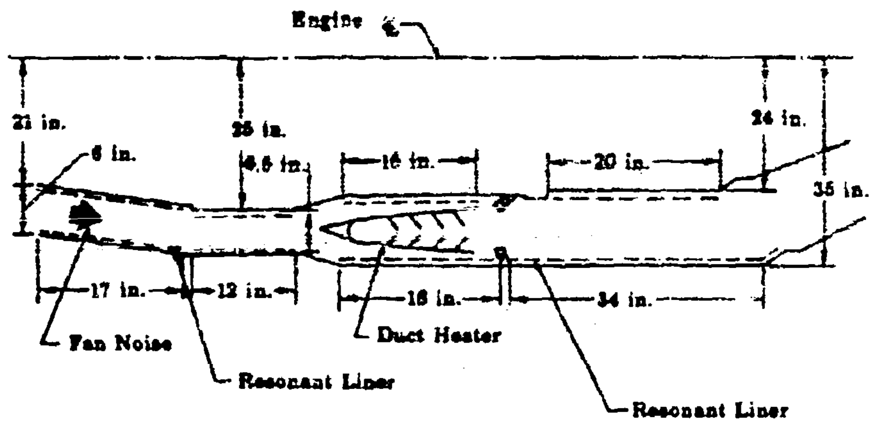


Figure 9. Potential Surfaces for Treatment With Acoustical Liners FD 16825 CIII

One of the most attractive approaches includes the use of an acoustically treated flowsplitter mounted on the existing radial supports just downstream of the fan discharge (figure 10). By treating the supports and replacing the existing duct walls with a honeycomb structure having acoustical treatment, an effective L/D of approximately 4 would result. The added improvement in noise suppression that, using a flowsplitter, may be gained by incorporating absorption liners on the diffuser support strut surfaces is shown in figure 11. These data were acquired from rig tests similar to those previously described. It is anticipated from the data presented above that this design will result in JTF17 engine fan noise attenuation of about 15 db per octave band. If a honeycomb-type structure were used, the weight of this installation would be approximately five pounds per engine. It has been decided to use an acoustically treated flowsplitter in the SST engine.

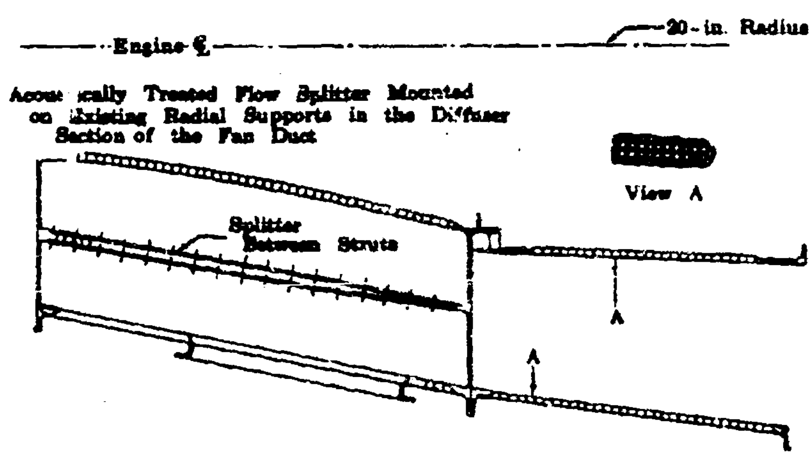


Figure 10. Acoustically Treated Flowspitter Mounted in Diffuser Section of Fan Duct FD 16824 CIII

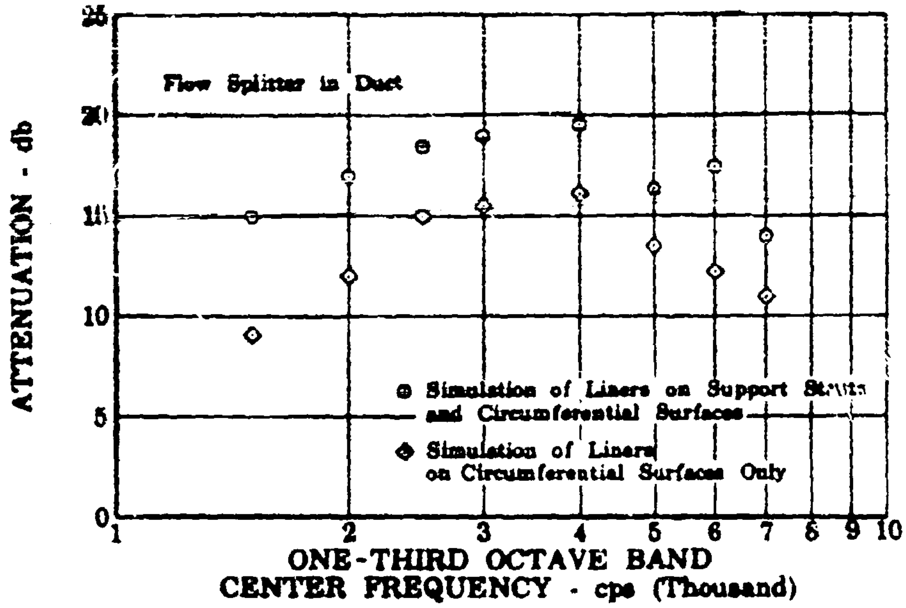


Figure 11. Effect of Absorbing Liners on Diffuser Support Struts — FD 16823 CIII

Additional suppression of fan noise, if required, is available through the use of additional acoustical liners. Honeycomb structure techniques with acoustical treatment can be used in other sections of the fan duct to replace sections of the existing duct walls with little or no weight penalty.

3. Fan Design Modifications

a. Blade/Vane Matching

Theory developed by P&WA indicates that suppression of discrete frequency noise produced by a compressor can be accomplished through the proper matching of the numbers of blades and vanes. Summarizing the theory, fully developed in U.S. Patent No. 3,194,487, the pressure modes generated by the interaction between rotating blades and stationary vanes can be made to rotate at subsonic speeds with proper selection of blade and vane numbers, regardless of blade tip speeds. To achieve this condition, the number of vanes should be slightly more than twice the number of blades. Under this condition, the pressure modes will decay in the duct and not be emitted from the engine through the inlet or fan discharge ducts. These pressure modes manifest themselves as discrete frequencies that, for the JTF17 engine fan, represent a major noise source.

Tests have recently been completed on a P&WA model JT9D engine to illustrate the above principles. For the base case, 48 guide vanes were used with a 46-blade rotor. A reduction of as much as 12 db in measured noise using 96 vanes with the same rotor is shown in figure 12. These amounts of attenuation resulted from an almost complete elimination of discrete frequencies with the 96-vane stator.

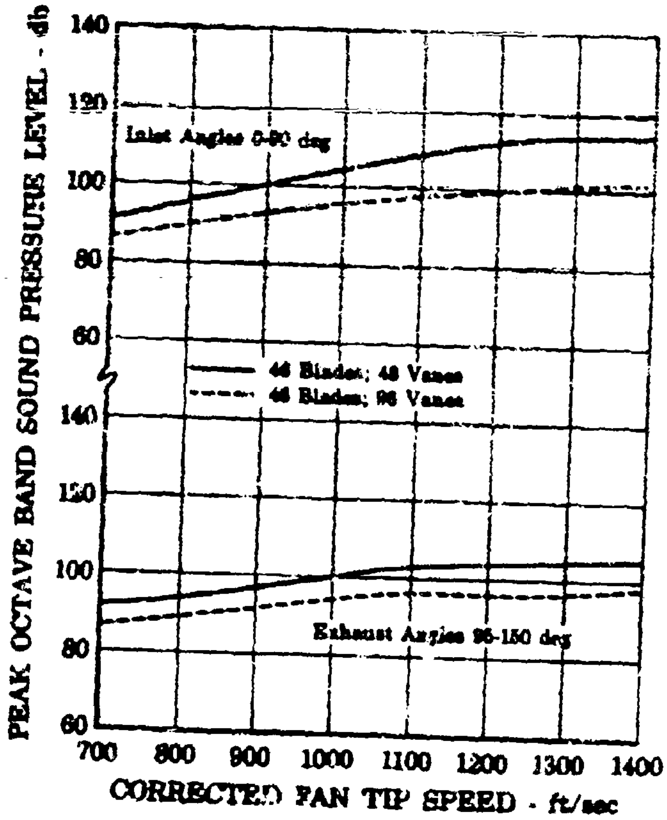


Figure 12. Effect of Exit Vane Number on Fan Noise

FD 16822
CIII

The second stage of the JTF17 engine fan has been designed with 74 blades and 154 vanes. Due to the similarity to the JT9D engine configuration in blade/vane ratio, this can be expected to reduce the noise produced by the second stage of the fan by 6 to 8 db through direct control of the discrete frequencies and the harmonics.

Application of this technique to the first stage of the JTF17 engine is under consideration. As a result of the axial spacing between the blades and vanes that now exists in the fan design (see paragraph 3.b), the addition of blades for noise control may not be necessary. The possibility of applying this method of suppression here, however, exists.

b. Spacing

Noise research work conducted by P&WA and other companies has established that the spacing between the blades and vanes is a means for controlling the amplitude and frequency of discrete frequency noise produced by a compressor fan.

An axial spacing distance of 120 percent of chord length has been chosen for the first stage of the JTF17 prototype fan. From figure 13 it can be seen that this spacing is expected to produce approximately 4 db reduction

in fan noise. This is accomplished through a reduction of the discrete frequency noise associated with the fundamental frequency of the first rotor and its harmonics and is relative to current commercial engine spacing of approximately 40 percent. This modification to initial fan design is expected to increase engine weight by about 5 pounds.

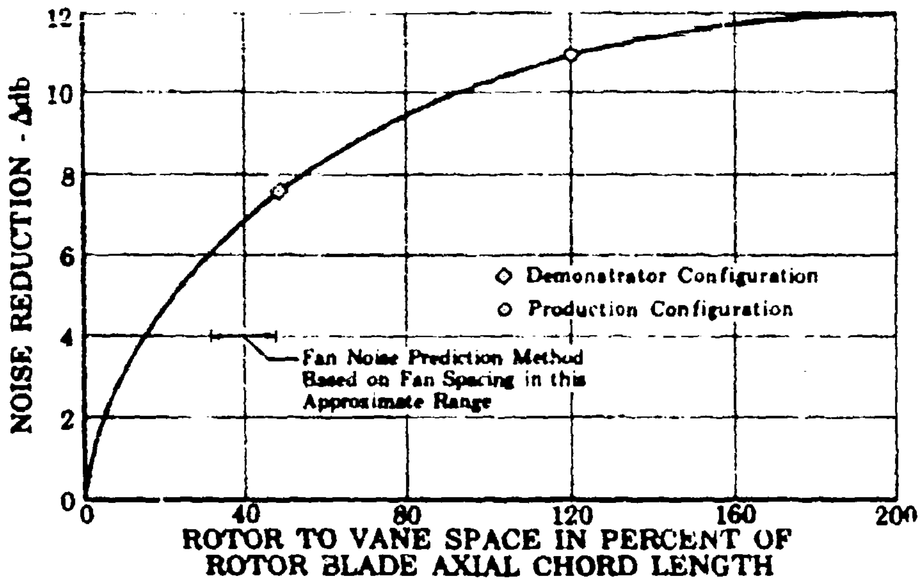


Figure 13. Effect of Fan-Vane Spacing on Fan Noise FD 16786 CIII

Although the relationship presented in figure 13 was generated at subsonic rotor tip speeds, recent tests conducted at the P&WA facility in East Hartford indicate that similar beneficial effects will result at supersonic speeds. The effect of rotor speed is summarized in table 1, for subsonic, approximately sonic, and supersonic rotor tip speeds. Throughout the rotor tip speed range shown, reduction in the sound pressure level of the fundamental blade passing frequency transmitted downstream remained constant following an increase in spacing.

c. Inlet Guide Vanes

The JTF17 engine fan design reduces the engine noise level because the design does not incorporate inlet guide vanes. Tests recently conducted by P&WA on the JT9D engine provided a full-scale demonstration of the effects of inlet guide vanes on fan-generated noise. Data from these tests have been incorporated into a simulated flyby condition, which is presented in figure 14. Similar beneficial effects are expected to accrue from incorporation of these results into the JTF17 engine fan design.

Table 1. Effect of Spacing Upon Discrete Frequency Fan Noise

(Spacing Increased from 37% to 74% of Blade Chord Width)

Rotor Tip Speed - ft/sec	Reduction in Sound Pressure Level - db: Noise Transmitted Downstream		Noise Transmitted Upstream	
	Fundamental Blade Passing Frequency	First Harmonic	Fundamenal Blade Passing Frequency	First Harmonic
950	7	0	14	4
1100	7	4	9	11
1290	7	1	6	7

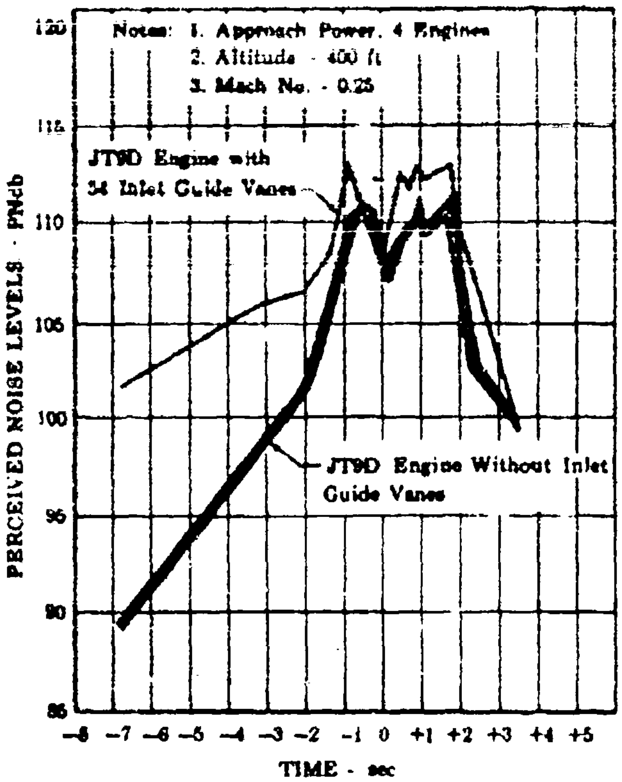


Figure 14. Flyover Noise Level Comparison FD 16785
CIII

C. EXHAUST NOISE SUPPRESSION

1. Methods Available

Three methods of exhaust noise suppression are available for the JTF17 engine. Sound suppressors similar to those now used on other P&WA commercial engines will be fitted to the engine to provide at least 4 PNdb suppression of exhaust noise. Designs are now being developed that will allow the removal of these devices from the exhaust stream at cruise and thereby improve cruise performance. Exhaust noise suppression of 4 PNdb will also be provided by the ejector action of the reverser-suppressor. In addition, resonant acoustical liners will be installed along the inner walls of the ejector to provide suppression of both fan-generated noise and that noise produced by the exhaust gases. This is expected to provide about 2 PNdb reduction in engine noise.

2. Noise Suppression from Ejectors

a. Test Data

Substantiation of a blow-in door ejector as an effective noise suppression device has been provided by several tests. Noise levels of the YF-12 aircraft, figure 15, have been measured by sound personnel from

P&WA and the airframe manufacturer. In this installation, although structurally part of the airframe, the ejector also operates as an integral part of the engine exhaust system. An ejector, constructed for static noise tests at P&WA's FRDC, closely duplicated the geometry of the flight version (figure 16). Further duplication of the YF-12 test conditions was provided with the installation of a supersonic inlet and an engine nacelle (figure 17). For comparison, noise levels of the J58 engine without inlet, nacelle, or ejector were recorded at both locations.

The results of these tests are summarized and compared to predicted values in figure 18. The recorded data has been adjusted to a common value of nozzle area and exhaust gas density to enable direct comparison and to eliminate inlet installation effects.

Relatively good agreement is shown between the baseline tests (without ejector) and the expected noise level based upon the SAE prediction system. This agreement exists throughout the augmented and nonaugmented thrust range. Installed and simulated installed noise values, in contrast, fall well below this level. In the augmented thrust range (relative jet velocity above 2400 ft/sec) data recorded from engine tests with the ejector installed are approximately 4 PNdb lower than predicted. This difference in the nonaugmented thrust range is approximately 3 PNdb. No special acoustical treatment was applied to the ejector during these tests.

These observations are not unique. Numerous other reports indicating that noise attenuation has been gained with the use of ejectors have been published. Some of these reports are summarized in table 2.

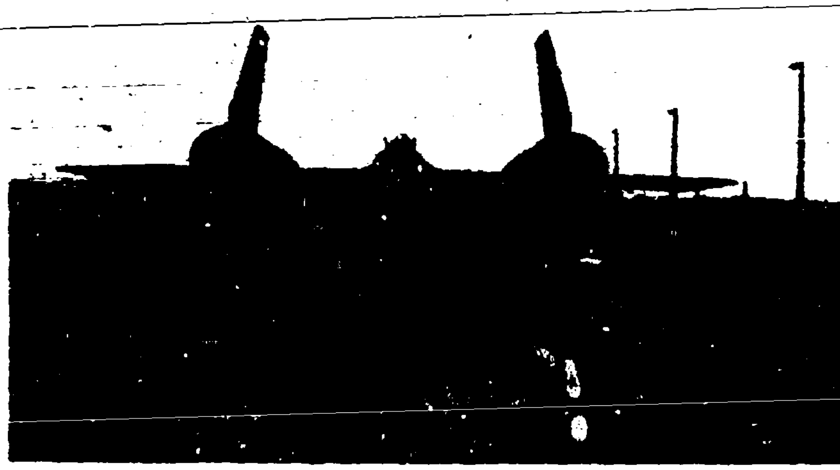


Figure 15. Tie-Down Stand Used During Installed J58 Noise Tests — FE 61997 CIII

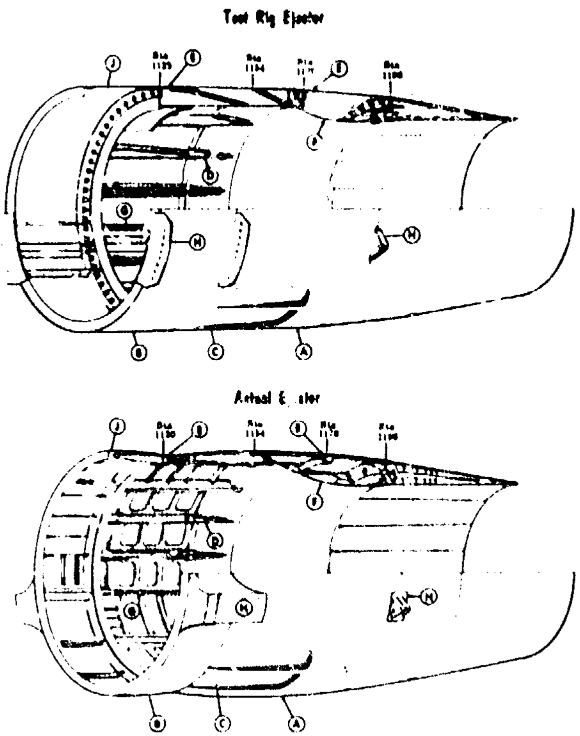


Figure 16. Test Rig Ejector

FEATURE A. EXTERNAL CONTOUR STA 1130 TO 1196

Flight contour is barrel shaped. Test rig was made cylindrical keeping the same OD as the forward edge of the ramp at STA 1154. Cylindrical section extends from STA 1125 to about STA 1170. From STA 1170 to 1196 the rig was made a cone with the same dia at STA 1196 as the flight version.

FEATURE B. EXTERN..L CONTOUR - FORWARD DUCT SECTION

On the flight version this contour is also a barrel shape. On the test version it was made cylindrical and a continuation of the blow-in door section cylinder. The rig version is slightly smaller than the flight version and its length was chosen as about 24" to be sufficient influence on air coming toward the blow-in doors.

FEATURE C. BLOW-IN DOORS

Fli ht doors are hinged at about STA 1130 and when blown in, for a smooth outer contour from STA 1125 to STA 1154 coming to rest against stops riveted to the sides of the struts between the doors. On the rig the doors are cut from the cylinder outer surface and pushed in to the same opening and riveted to the struts in this fixed position. This method of obtaining the door resulted in a 2° change in the trailing edge angle of the door. The door openings are the same size and number and are located in the same circumferential positions.

FEATURE D. STRUTS

The flight struts are tapered being smaller at the forward end. The rig struts have constant radial height equal to the max height of the flight struts. The rig struts are as close as possible to the flight strut cross section but still allow them to be made by folding up one piece of sheet metal. The rig struts are all alike whereas the flight item uses smaller struts on each side of the shear panels.

FEATURE E. FORE AND AFT STRUCTURAL RINGS

The flight version has forged rings at STA 1130 and 1178. The rig has rings made of rolled up structural angle located at STA 1125 and 1170, both having the same OD. The front ring had to be moved ahead to be just in front of the blow-in door contour. The front ring on the rig has a cylindrical piece attached to provide the same air blockage at STA 1130 as the flight ring does. The rear ring is located at the cylinder-cone junction.

FEATURE F. INTERNAL CONTOUR STA 1154 TO TAIL

The conical ramp on the rig is identical to the flight item. The throat spool piece has the same contour, material and thickness and has a similar mounting. The flight version supports the throat on machined rings whereas the rig uses sheet metal rings but of the same stiffness. The tail section is conical inside, one piece, with a fixed exit. The flight version has 12 movable flaps that are conical at the minimum exit opening. The material in both cases is Hastelloy from STA 1154 to the end and structural stiffness is duplicated throughout.

FEATURE G. SHEAR PANELS ACROSS THE BLOW-IN DOOR SECTION

The flight version has 3 ribbed panels. One on each side just below the horizontal centerline and one near the top centerline to distribute an externally applied load. On the rig only the 2 side panels are stiffened. The top panel is not stiffened since it is not a load carrying member on the rig.

FEATURE H. MOUNTING PROVISIONS

On the flight item all the duct forward of STA 1130 is mounted in the wing which is in line with the lower shear panels. A redundant clevis type mount is located at STA 1178 where the ring is. The rig is mounted on the forward duct section on 4 large brackets in the wing location. The redundant clevis mount was located at the new ring location, at STA 1170.

FEATURE J. GENERAL SKIN CONSTRUCTION

The flight item uses a skin of light gage titanium reinforced with titanium ribs. The rig skin is heavier gage carbon steel, reinforced only in areas carrying mount loads

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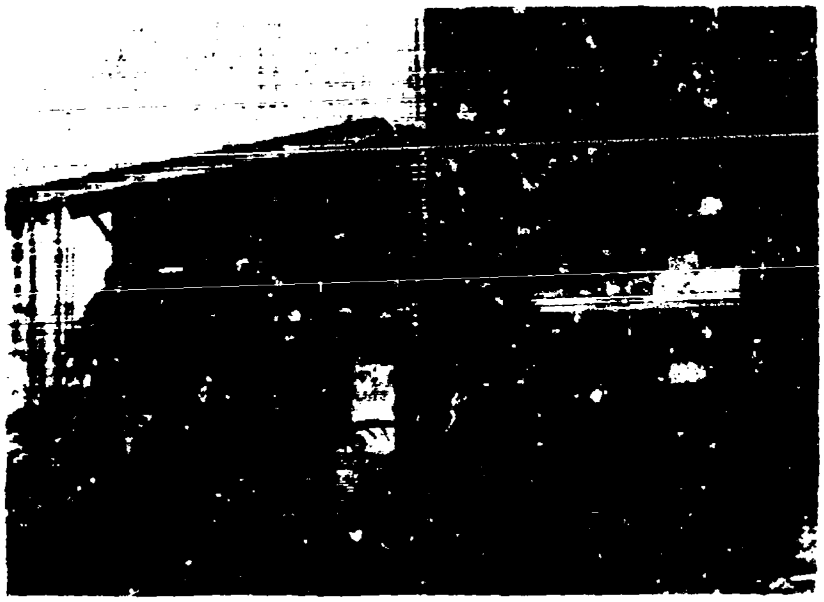

Figure 17. Simulated Installed J58 Engine Noise Test Configuration — FE 61228 CIII

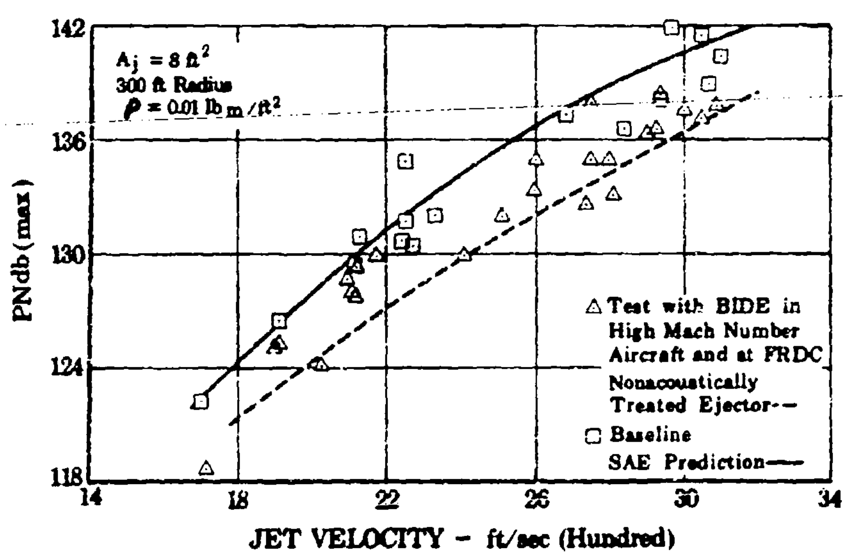

Figure 18. J58 Sound Survey — FD 17817 CIII

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Table 2. Reports Indicating Noise Attenuation by Ejectors

Report	Date	Test Apparatus	Ejector L/D	Thrust Change	ΔSPL (ref 0.0002 dynes/cm^2)
NACA TN-4261	Apr 1958	Full-size Engine	1.33	-9%	-8
NACA TN-3573	Oct 1955	Full-size Engine	1.5	0	-2
NACA TN-4317	Aug 1958	Full-size Engine	N/A	+2%	-9
NACA TN4317	Aug 1958	Full-size Engine	2.4	+5%	-11
NACA TN-D-814	Aug 1961	Full-size Engine	1.15	-3.5%	-9
SAE Prepr. 818	Oct 1956	Model	N/A	N/A	-11
Boeing Co. 6-7719-5	May 1966	Model	N/A	N/A	-8.5 (PNdb)

As a result of these and similar successful applications of ejectors to the problem of noise control, P&WA instituted a program to define the ejector characteristics that cause the suppression measured. This program is described in paragraph C.3.

During the FRDC ejector tests referred to above, pressure transducers were installed along the inner ejector wall (figure 19) to measure the incident acoustic energy. Narrow frequency band analysis of this data (see figure 20) indicated a high acoustic power concentration centered at about 1500 cps and encompassing mainly the fifth- and sixth-octave bands.

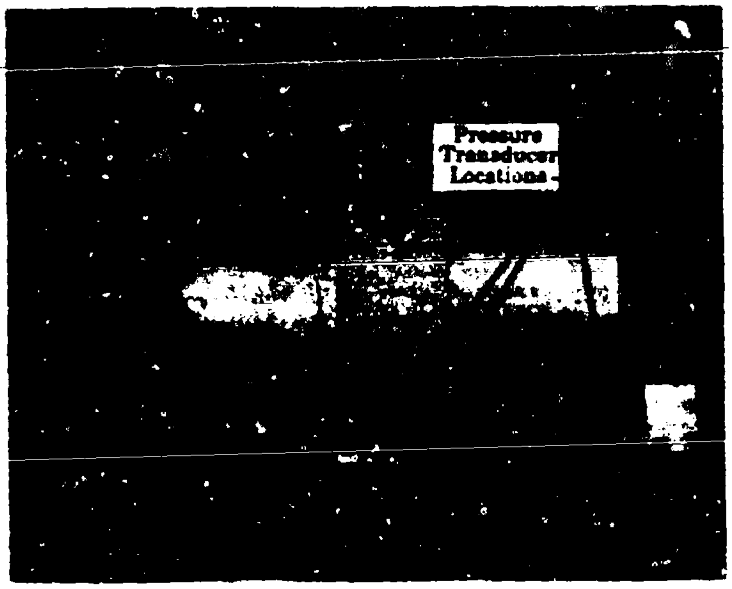


Figure 19. Pressure Transducer Locations in J58 Test Rig Ejector

FD 17825
CIII

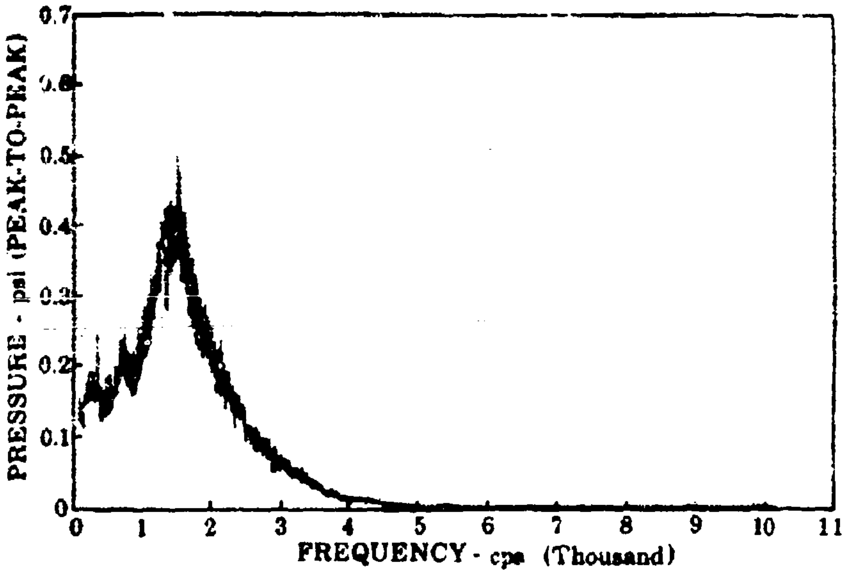


Figure 20. Spectral Analysis of Exhaust Noise at the Inner Surface of the J58 Test Rig Ejector — FD 17826 CIII

Further analysis indicates that acoustic liners installed along the inner surface of the ejector would absorb a significant amount of noise. Ideal conditions for the application of this technique exist due to:

1. The relatively high sound pressure levels (about 160 db) at the liner surface
2. Relatively low velocities (about 350 ft/sec) adjacent to the liner surface due to the introduction of tertiary air from the ejector blow-in doors
3. The small hole sizes and low percent of open surface area required that will have no effect on ejector performance.

b. JTF17 Engine Application

The reverser-suppressor of the JTF17 engine is similar in design to the ejector used on the J58 engine in the above tests. In each case, blow-in doors are used in conjunction with movable flaps at the downstream edge of the ejector. Although the exact nature of the mechanism by which the ejector provides attenuation of noise is unknown, the potential exists for achieving exhaust noise suppression with the JTF17 engine of the same magnitude as observed during the tests previously described.

This su pression will be further enhanced through the use of resonant acoustical ers in the ejector. Tests to evaluate this method of exhaust noise attenuation are now being conducted. It is anticipated that a reduction in sound pressure level in the fifth- and sixth-octave bands of 5 db is attainable; this will provide an overall noise reduction

of about 2 PNdb during augmented engine operation. An additional benefit is anticipated with low nonaugmented power operation through the attenuation of fan noise as well as the noise from the exhaust gases.

3. Ejector Noise Effects Analysis

P&WA experimental results show that the simple application of an ejector to an exhaust system does not necessarily guarantee acoustic superiority. The suppression mechanism is complex, depending subtly on both the geometric and dynamic conditions of the entire exhaust system. It has long been thought that the acoustic power emitted from an exhaust jet could be substantially affected by altering the means by which the primary stream mixes with the ambient air into which the steam discharges. This, then, would imply an alteration of the mechanism that gives rise to aerodynamically generated exhaust noise. That the nature of the mixing process should exert such a profound influence can be concluded from the work of Dr. Alan Powell.* In his analysis, Dr. Powell treats the jet exhaust as three distinct regions. The first region is defined by a linear growth of the annular turbulent region from its point of inception at the exit plane of the nozzle downstream to the point where the turbulence intersects the engine centerline. Following a short transition region (Region 2), the flow develops to fully turbulent in the final region.

It can be shown that for Region 1, that

$$P = KA$$

where:

P = acoustic power radiated from Region 1 (watts)
A = shear area of Region 1
K = constant

The constant, K, in this equation is an algebraic function of the ambient density, the ambient acoustic velocity, the jet velocity in the potential cone, and the exit diameter of the jet. This region is precisely that from which the highest frequency sounds are radiated. Understandably, an increase in the rate of growth of the annular turbulence region (which implies a decrease in the shear area of Region 1) would result in a decrease of an acoustic power that is radiated from this region. Because this decrease is felt predominantly at the high frequencies, the perceived noise level, which weights the higher frequencies more than the lower frequencies, should exhibit a substantial reduction.

* Theory of Vortex Sound, cf., The Journal of the Acoustical Society of America, Jan 1964.

Application of this theory has resulted in the development of several different types of mixing nozzles, such as those presently being used on some Douglas DC-8 and Boeing 707 aircraft. These configurations are successful from an acoustic standpoint, but they are generally accompanied by losses in performance as well as by weight penalties. An optimum configuration would be one in which the rapid growth of the turbulent mixing region occurred naturally as a byproduct of the normal expansion process of the exhaust system, rather than being forced to occur. The tests previously described indicate that a properly designed ejector might provide this type of mixing since the ejector did produce considerable noise attenuation.

To proceed with Dr. Powell's hypothesis, an investigation was undertaken by P&WA to examine the rate of growth of the turbulent mixing region associated with the J58 turbojet engine-ejector exhaust system. A means by which the gas flow could be visualized was needed; for this reason the hydraulic analogy of the water table was used.

Cross sections of the J58 engine were tested on the water table with and without the blow-in door ejector. It was observed that the flow patterns with the ejector in place and with tertiary flow were altogether different from those in which the engine exhausted to ambient atmosphere. The military power J58 water table test depicted in figure 21 shows that with no ejector the vortices generated at the lip of the primary nozzle are small and, therefore, leave at a high rotation velocity. The width of the turbulent mixing region is relatively narrow and diverges from the centerline of the engine. This indicates a large potential cone of high frequency noise. Figure 21 also shows the same engine setting with the ejector installed and with tertiary flow. Because of the convergence toward the centerline, the vortices are larger, the width of the turbulent mixing region is wider, and the potential cone is much shorter. These are the theoretical characteristics that should produce lower frequency, less objectionable jet exhaust noise.

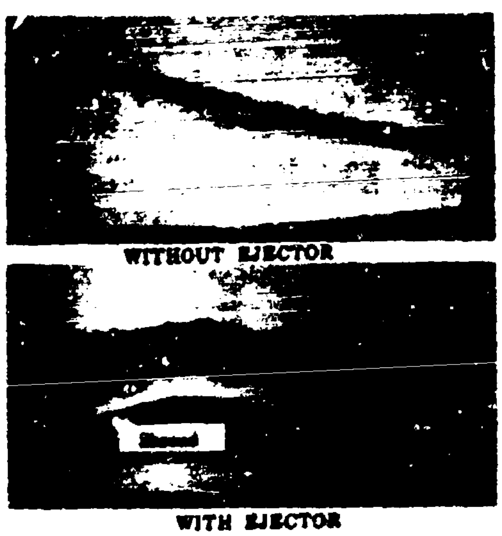


Figure 21. Water Table Test of J58 Exhaust System FD 16699 CIII

Results of additional water table tests with other nozzle and ejector configurations also showed that the rate of growth of the mixing region was greatly increased by the application of the blow-in door ejector configuration. Because the installed J58 engine employs the blow-in door ejector in its normal exhaust system (as does the JTF17 engine), the associated noise reduction is obtained with no performance or weight penalties.

Model testing and full-scale engine testing programs were conducted by P&WA to validate the above observations. The 1/14-scale J58 turbojet-ejector model, which was constructed and tested during contract Phase II-B*, was modified at the FRDC and retested in the P&WA anechoic chamber at East Hartford, Connecticut. Modifications were made to allow testing at higher jet velocities and to allow for secondary air (under pressure) to be introduced through an annulus around the primary nozzle to promote mixing of the primary and tertiary airstreams. Geometric modifications were made as dictated by the results of the water table. A 3 db reduction in perceived noise was measured. Somewhat larger values of attenuation were acquired with full-scale engine tests incorporating similar ejector geometry, as previously discussed.

All ejector design characteristics contributing to noise suppression have not yet been isolated. Therefore, while tests conducted during Phase II-C of the SST engine development program show that a 4 PNdb improvement can now be achieved, continuation of the program is planned for Phase III to develop detail design characteristics.

4. Jet Noise Suppressors

a. Test Data

Tests conducted by P&WA of the noise attenuation resulting from jet noise suppressors in current commercial use indicate that a maximum reduction of 6 PNdb is obtained. Peak PNdb on a line 200 ft from and parallel to the engine centerline is shown in figure 22 as a function of relative exhaust velocity for P&WA engine models JT3C and JT4A. With each model, suppressor efficiency improves with increased relative exhaust velocity. Static thrust reduction amounted to 3 to 4%.

An extensive investigation of potential noise suppressor designs for the JTF17 engine has been initiated by P&WA and is being conducted through model tests in the East Hartford anechoic chamber. Designs evaluated during the initial phase of this program are illustrated in figure 23 and identified below.

1. Near row (left to right):
   a. conventional nozzle
   b. conventional nozzle
   c. 4-lobe; 50% penetration**; medium length lobes
   d. 6-lobe; 75% penetration; long length lobes.

*cf. Phase II-B; Final Report - Item 8
**Duct annulus area remains constant, but minimum radial clearance between the duct nozzle and primary has been reduced to 50% of its original value.

2. Middle row (left to right):

   a. 4-lobe; 50% penetration; long length lobes
   b. 6-lobe; 50% penetration; long length lobes
   c. 4-lobe; 75% penetration; long length lobes
   d. 4-lobe; 50% penetration; short length lobes.

3. Far row (left to right):

   a. 12 flap sawtooth nozzle; long length
   b. 6 flap sawtooth nozzle; long length
   c. 12 flap sawtooth nozzle; short length
   d. 6 flap sawtooth nozzle; short length.

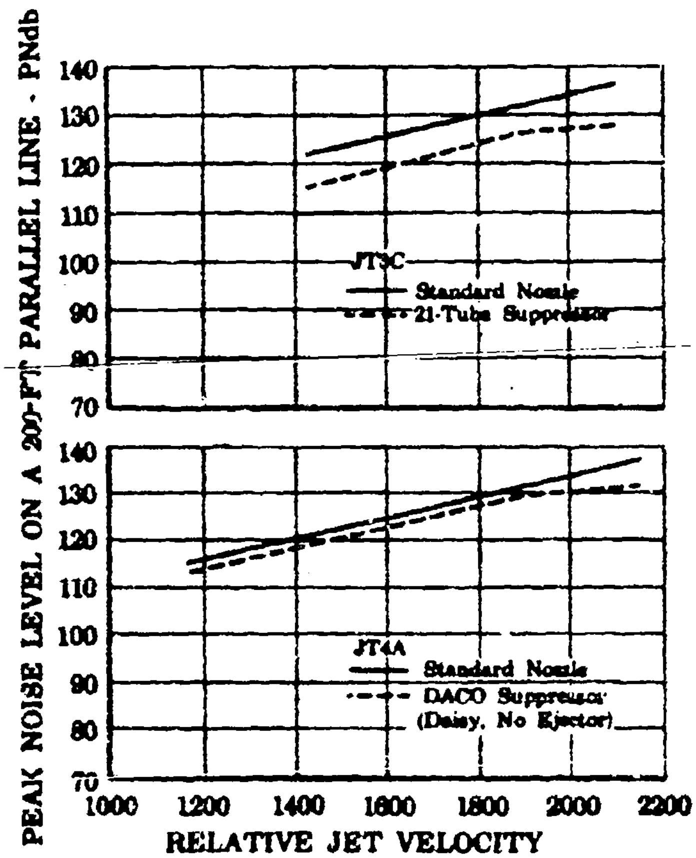


Figure 22. Suppressor Noise Reduction

FD 16784
CIII

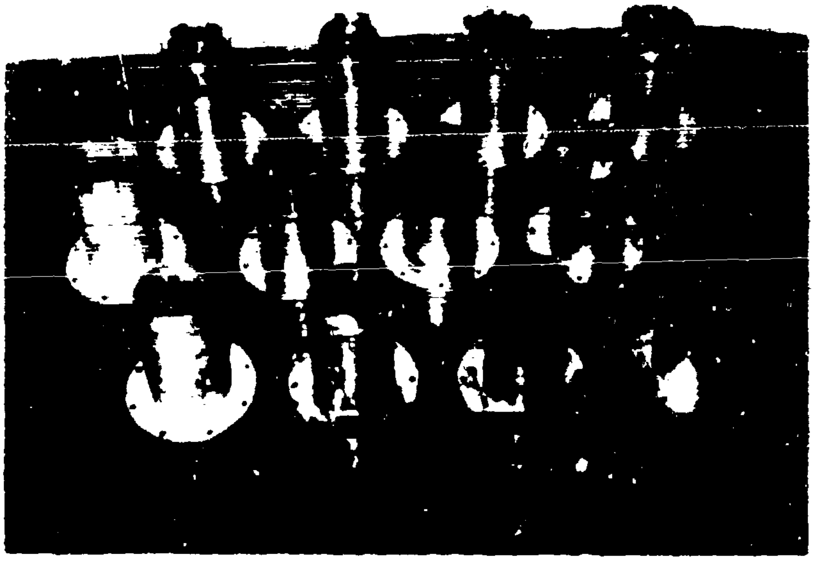


Figure 23. Scale Model Noise Suppression Nozzles FE 61995 CIII

Closeup views of lobed and sawtooth designs are shown in figures 24 and 25.

Each of these designs incorporates features to provide varying degrees of mixing between the tertiary air entering the reverser-suppressor blow-in doors and the duct exhaust gas. Several factors indicate that suppressors should be located here rather than the primary nozzle:

1. Due to the existing variable duct nozzle geometry, potential is provided here for retraction of suppressors during cruise to improve nozzle performance with minimum additional mechanical complexity and weight.
2. During augmented power operation, noise produced by the duct exhaust gas dominates that produced by the primary stream. Reduction of this noise source will provide a greater benefit in the reduction of total engine noise for this reason.
3. During nonaugmented power operation (normal schedule), duct burning can be used to increase the noise level of the duct exhaust gas and reduce that of the primary. This produces a situation similar to that described in item 2, above, while also providing the noise benefits described in paragraph C.5.

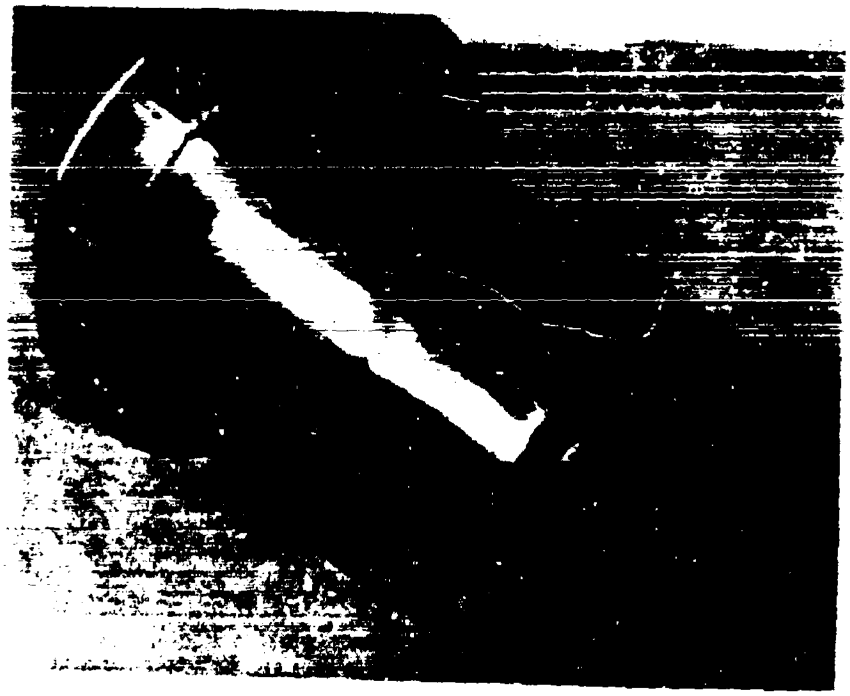


Figure 24. Suppressor Model 6 Lobe; 50% Penetration - Long Length

FE 61991
CIII

Figure 25. Suppressor Model 12 Flap Saw-tooth Nozzle - Short Length

FE 61989
CIII

b. JTF17 Engine Application

At maximum thrust, the relative velocity of the duct exhaust will be about 50% greater than that of nonaugmented engines now equipped with suppressors, thereby making improved suppressor efficiency possible. Conversely, with improved suppressor efficiency, designs that exact smaller thrust penalty (affect a smaller proportion of the exhaust stream) may be used to provide the attenuation required.

Although the technical feasibility of using a standard tube or daisy suppressor for attenuation of jet noise has been established in other engine development programs, several alternative methods that appear promising are under review. Two possible designs in addition to those described above are shown in figures 26 and 27; these designs may provide noise attenuation without affecting cruise performance.

By providing an irregular trailing edge to the clamshell of the ejector, an exhaust nozzle similar to a standard multilobed daisy suppressor is formed as shown in figure 26a. The ejector position shown is that used for takeoff. At a Mach number of approximately 1.2, the ejector assumes the position shown in figure 26b, providing a smooth ejector contour for optimum performance under conditions where engine noise suppression is not necessary. Adjustment of the clamshell angle is obtained by an actuation system that is sensitive to the position of the ejector blow-in doors. Flexibility thus exists to adjust the clamshells at low flight speeds (and altitudes) to an angle to provide the required amount of suppression.

A second design (figure 27) also utilizes the principles of a standard daisy suppressor and is automatically removed from the jet exhaust path at cruise. During acceleration (M = 0.12, approximately), the pressure differential across the ejector blow-in doors causes them to remain in the open position (figure 27a). By providing a hinged guide plate and lobes as shown at the end of the doors, tertiary air can be forced to mix with the exhaust gas from the high-velocity fan-duct stream. Deep penetrations similar to those provided by a daisy nozzle could be assured by a series of latches set prior to takeoff to hold the doors in their maximum open position. Because of the extremely high velocity of the fan duct exhaust at augmented power settings and resultant improvement in suppressor efficiency (figure 22), requirements for penetration would be smaller than that for current commercial jet suppressors.

Under cruise conditions, automatic closing of the blow-in doors would cause the tertiary-air guide plate to retract and remove the suppressor lobes from the path of the exhaust gases (figure 27b).

An additonal nozzle design that, with an ejector, has been shown to provide attenuation of 6 to 8 PNdb (NACA TN-4261) is illustrated in figure 28. Either the clamshell, variable area duct nozzle, or the trailing edge of the blow-in doors could be designed to incorporate this feature, which, as described for the previous two designs, would not be detrimental to performance at cruise.

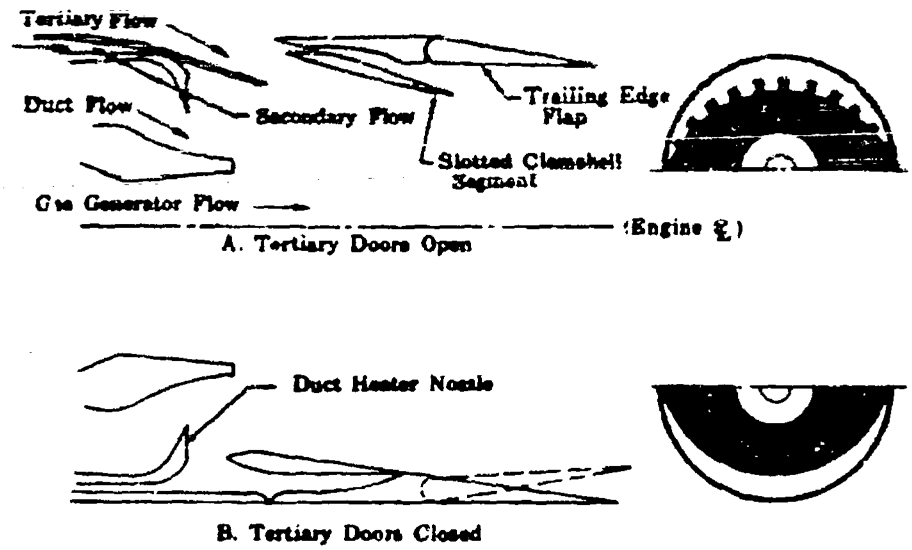


Figure 26. Adaptation of Clamshell Ejector for Exhaust Noise Control FD 16783 CIII

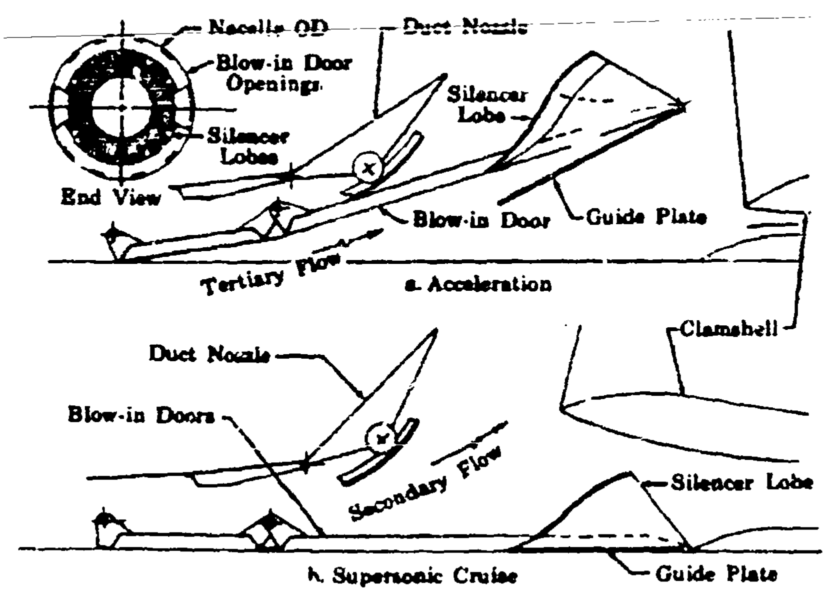
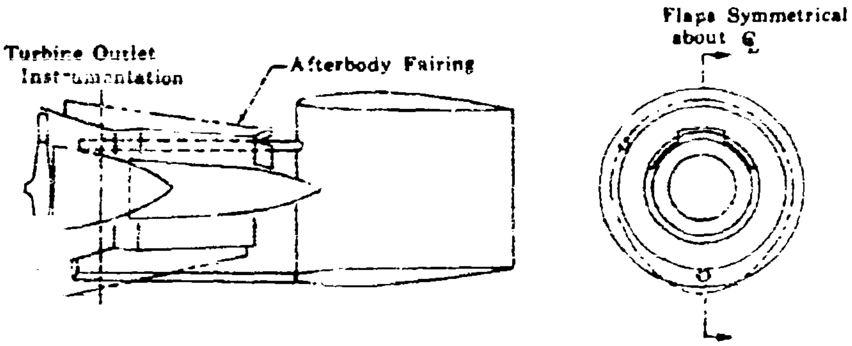


Figure 27. Adaptation of Blow-In Doors for Exhaust Noise Control FD 16782 CIII



Reference: NACA TN 4261

Figure 28. Mixing Nozzle With Ejector

FD 16781
CIII

5. Operational Techniques for Suppression

As shown in figure 3 of Section II, under the power conditions expected to exist at power cutback following takeoff, considerable mismatch exists between the individual engine noise sources. Improved matching of these sources obtained through the use of duct heating has been shown analytically to be beneficial in reducing engine noise.

Specifically, the operation of the duct heater offers three potential matching advantages. First, by providing more thrust from the fan duct exhaust, primary thrust can be reduced and the required engine thrust still maintained. Jet noise produced by the primary and duct jets can be matched closely by this method. Second, by reducing the primary thrust output, fan speed will also be reduced with attendant reductions in noise contributed by the fan. Third, by applying this technique during power cutback after takeoff, the range between fan speeds at this flight condition and at airport approach will be minimized. Since acoustical liners must be designed for a limited range of fan speeds to provide optimum noise attenuation (shown as a function of frequency in figure 5), this permits the use of one liner design under both flight conditions.

The results of an analysis of the noise attenuation value of this technique for typical flight conditions following power cutback at takeoff are shown in figure 29. Reductions in rotor speed that were acquired through reduced primary fuel flow (from about 6140 to 5700) are reflected in the use of 13 db fan noise attenuation. This would result if acoustical liners used in the fan duct were designed for fan speed at airport approach (15 db attenuation at about 5450 rpm). Under this mode of operation, total engine noise has been reduced by 5 PNdb at a duct fuel/air ratio of approximately 0.005.

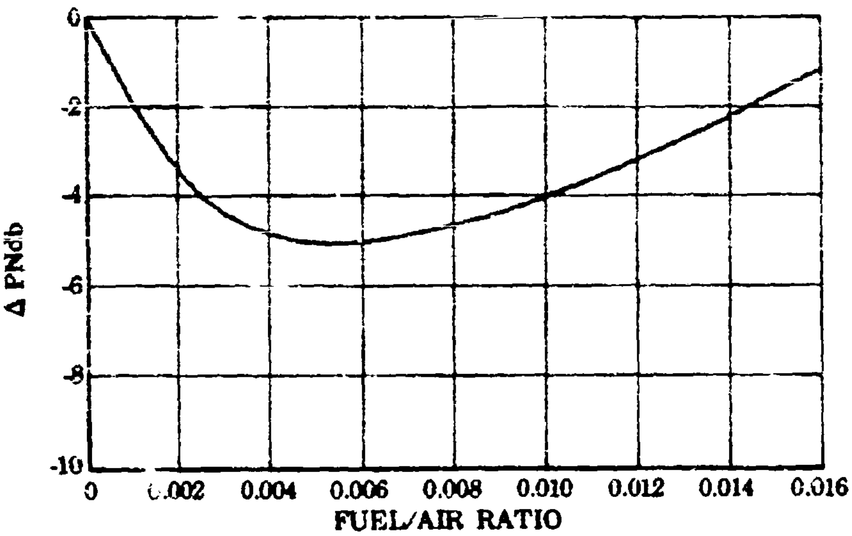


Figure 29. Typical Reduction in Total Engine Noise With Duct Heater Operation at Thrust Cutback After Takeoff — FD 17900 CIII

From these analyses it is clear that duct heating will provide significant noise improvement at low thrust levels through reduced rotor speed and improved matching of jet noise. An optimum duct burner fuel flow schedule will be established by actual engine tests.

Means will be provided to permit duct heater operation at reduced gas generator speeds to achieve the above results. Flight crew action will permit duct heater operation to be continued as the power lever is decreased below the normal duct heating regime. Duct fuel flows will be scheduled to the level required to obtain the desired noise reduction. Termination of duct heater operation in this reduced speed region will be accomplished by flight crew action.

D. SUPPRESSOR DEVELOPMENT PROGRAM

1. Introduction

This program will be conducted simultaneously in the following three areas:

1. Fan design modifications
2. Acoustical liner development
3. Exhaust noise suppressor development.

The facilities to be used and the program requirements in each of these areas are described in this section. This development program will apply noise suppression techniques of established merit to the fullest extent possible to the suppression of JTF17 engine noise.

2. Fan Design Modifications

The effect of several possible fan design modifications will be evaluated using the full-scale compressor rig. The specific objectives of this program will be to optimize the selection of fan vane numbers and of the spacing between the blades and the vanes in the first stage of the fan. Additional programs will be developed as required by the noise development program previously discussed (Section II.B).

During the operation of the fan rig, sound recordings will be made using a microphone placed in the airflow discharge duct. This data will be analyzed using narrow-band frequency filters to define the amplitude and frequency of pressure peaks generated by the fan.

Spacing between the first stage rotor and stator will be altered in small increments about the value of 120% of blade chord length. Vane numbers will also be varied. Throughout this program, sound recordings will be made and the resultant analyses compared. The best configurations selected from this program will be verified in full-scale engine tests. The requirements of this program are further defined below. Sound measurements for each program will be taken at 5 increments of rotor speed between 4000 and 5000 rpm, since fan noise is predominant in this speed range.

a. Spacing of First-Stage Rotor/Stator

Different axial spacing distances between the first-stage rotor and stator will be evaluated with the full-scale fan rig. The spacing will be varied from 100 to 140% of the 1st-stage blade chord length.

b. Number of 1st-Stage Vanes

Using the optimum 1st-stage rotor/stator spacing from the above tests, the effect of varying the number of 1st-stage vanes will be evaluated. Stators with sets of vanes with varying numbers from 92 to 100 will be tested.

c. Number of 2nd-Stage Vanes

With the design of the first stage determined from the above tests, the number of 2nd-stage vanes will be varied between 152 and 160.

3. Acoustical Liner Development

This program will be divided into two separate studies. In the first, the selection and development of acoustical liner materials will be conducted with an impedance tube. In the second, the fitting of the selected material to the engine duct in segments that provide the most effective suppression of fan-generated noise will be conducted in full-scale engine tests.

The exact properties of a sound and the sound's environment must be accurately known to provide an optimum acoustical absorber design. These properties include the sound's frequency and amplitude as well as gas flow velocity, temperature, pressure, and density. With an impedance tube, a liner design can be selected that will provide the greatest amount of sound absorption under a given set of specific conditions.

The acoustical effectiveness of a material is stated in terms of the material's sound absorption coefficient, which is defined as the fraction of the incident sound energy absorbed by the material. The impedance tube is one of the most widely used methods for obtaining absorption coefficient data and provides a relatively inexpensive, fast, and accurate means of selecting material with optimum sound suppression characteristics.

The sound waves produced during impedance tube tests are transmitted in a direction normal to the surface of the material being tested. In contrast, a fan duct of the JTF17 engine will include diffuser sections with walls that are not parallel to the engine centerline, as well as turbulence inducers, burners, and other geometric conditions that will be dissimilar to the impedance tube. In addition, the noise introduced into the duct by the fan will have a random direction. In relationship to the effectiveness of acoustical liners in a fan duct, the following two conclusions can be made, which are reinforced by P&WA tests conducted during Phase II of the SST development program.

1. Although impedance tube tests can be used to select an acoustical liner with optimum absorption in the frequency ranges of interest, the amount of suppression that may result from the application of this material to a particular engine's fan duct cannot be accurately predicted.
2. To determine the amount of fan noise attenuation that can be obtained, tests must be performed with acoustical liners installed in the engine's fan duct (or an accurate rig simulation).

A combined analytical and experimental approach is used with the impedance tube to find the impedance of a liner configuration installed in the diffusion duct of the engine. A schematic diagram of the impedance tube setup is shown in figure 30. The impedance of the test sample is treated as being in series with the impedance of the flowing air behind the sample. The latter impedance value may be obtained by operating the impedance tube without a sample. The impedance thus obtained may be subtracted from the impedance obtained under flowing

conditions with the sample in place to obtain the impedance of the test sample. The total impedance of a liner configuration may be obtained by adding the test sample impedance to the calculated capacitance of the cavity behind the sample which is given by:

$$Z_b = i\rho c \cot (k_g L)$$

where:

ρ = density of free air
c = acoustic velocity of free air
K_g = propagation constant defined by $K_g = \frac{\omega}{c}$
L = thickness of air backing
ω = angular frequency of the incident sound = $2\pi f$

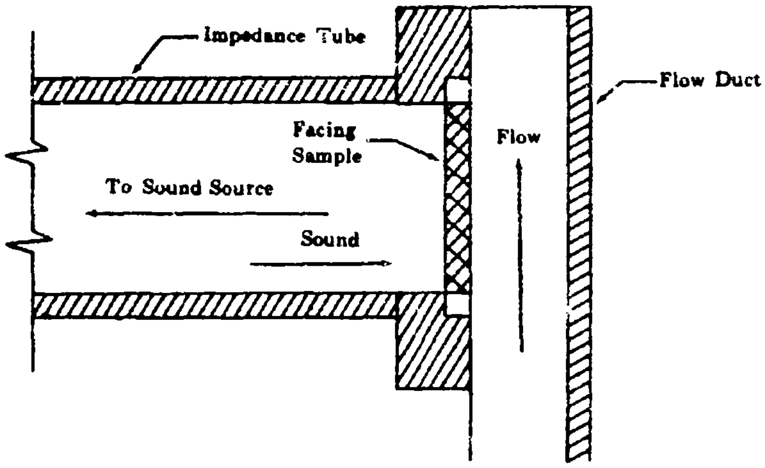


Figure 30. Schematic Design of Impedance Tube FD 16778 CIII

The backing impedance thus obtained is valid when the sound is either normally incident to the facing surface or where the air backing is divided into small cells by partitions (as would be accomplished by using a honeycomb-type of liner construction).

The impedance tube will be used in the selection of both resonant and nonresonant acoustical liners. As shown by figure 2, close agreement exists between analytical evaluation and impedance tube tests results for resonant materials.

The second phase of this program will consist of installed acoustical liner tests. The objectives of this program will be to:

1. Verify the results of the liner selection program
2. Determine optimum liner locations
3. Measure fan noise transmitted through the fan duct with the liners installed.

With regard to the first objective, circumferential liner selections of short axial length will be fitted to the fan duct just downstream of the fan. Several sections that provided different amounts of absorption in impedance tube tests will be compared for attenuation capabilities. Further comparison to impedance tube results will provide verification that the optimum liner selection has been made.

Optimum liner locations will be determined by measuring the attenuation of fan noise during engine tests. Small sections of liners will be placed and evaluated at such locations as:

1. The diffuser flowsplitter
2. The eight radial engine supports in the duct diffuser
3. The section of the duct just prior to the duct burners.

Three advantages are expected from this procedure. First, liners will be located in the final design only in the places where substantial suppression results. Second, it is expected that minor fan duct contour changes that can be incorporated early into the engine design may be suggested through this program of sequential changes. Third, the effect of each liner section upon the adjacent section can be checked. For example, a liner section located just downstream of the fan discharge will provide some suppression of fan noise. The exact amount of suppression that will result is not now known and must be determined through actual engine test. Due to the sensitivity of liner design to sound intensity, the next liner section must be designed to the exact conditions in its area. Thus, the design and check of liner sections must be performed in stages progressing downstream from the fan discharge. All of this activity will be fully evaluated during full-scale engine tests.

4. Exhaust Noise Suppressor Development

Analytical methods for the evaluation of the effect of exhaust system geometrical changes on the exhaust gas noise do not exist. All development work on exhaust noise suppression devices is therefore limited to the use of models or full-scale engine tests.

Suppressor configurations that may be used on the JTF17 engine were previously discussed in this section. Design and development work aimed at obtaining optimum attenuation will be conducted on the outdoor model test facility shown in figure 8 of Section II. This facility will also be used to evaluate the effect of the various operational techniques discussed. Models of the ejector system will be constructed and tested on this facility.

Sound recordings taken during these tests will be subjected to one-third octave band filter analysis and compared to tests of models without suppression devices.

Full-scale engine tests will be used to provide final evaluation of the attenuation provided by the most effective suppression devices found in the model test program.